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Joule-Thomson effects for carbon dioxide-methane mixture

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JOULE-THOMPSON EFFECTS FOR CARBON DIOXIDE-METHANE MIXTURES

by

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Professor in Charge

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Date

Head of the Department

D E D I C A T I O N

I wish to dedicate this thesis to my parents for a lifetime of sacrifices, my wife and children.

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LIST OF SYMBOLS

CAPITALS

A	Constant in Polynomials Fitting Isenthalp Data
B	Constant in Polynomials Fitting Isenthalp Data
C	Constant in Polynomials Fitting Isenthalp Data
Cp	Heat Capacity at Constant Pressure per Mole
Cv	Heat Capacity at Constant Volume per Mole
D	Constant in Polynomials Fitting Isenthalp Data
H	Molar Enthalpy
K	Interaction Constant
P	Pressure
R	Gas Constant
T	Temperature
V	Volume

LOWER CASE

a	Redlich-Kwong Constant
b	Redlich-Kwong Constant
w	Accentric Factor
y	Molar Fraction

GREEK LETTERS

α	Robinson and Jacoby Constant
β	Robinson and Jacoby Constant
γ	Robinson and Jacoby Constant
δ	Robinson and Jacoby Constant
$\sum$	Summation Sign
μ	Joule-Thompson Coefficient

θ Wilson Constant

ω Accentric Factor

Ω Prausnitz Constant

SUBSCRIPTS

P Refers to Constant Pressure

T Refers to Constant Temperature

V Refers to Constant Volume

c Refers to Critical Property of Pure Species

i Refers to Component i

ii Refers to Component i

ij Refers to Binary Interaction

j Refers to Component j

jj Refers to Component j

mix Refers to Mixture

12 Refers to Binary Interaction

o Refers to Zero Pressure State

SUPERSCRIPTS

o Refers to Zero Pressure State

ABSTRACT

A circulating system employing a throttling valve was used to measure Joule-Thompson effects in Nitrogen, and in one mixture of Carbon Dioxide-Methane. Heat leakage and kinetic effects were eliminated. The apparatus was checked for reproducibility with Nitrogen over a wide range of pressure and at a temperature of 294.92 ^{o}K. The average value of the Joule-Thomson coefficient was within 1.5 percent of prior literature values.

The thermocouples used to measure the inlet and outlet temperatures to the Joule-Thompson valve were calibrated by comparison with a resistance thermometer certified by the National Bureau of Standards. The observed outlet temperature-pressure pairs were fit to a polynomial expression with temperature as the dependent variable. The maximum deviation in any temperature reported in this project is o.12 ^{o}K, the average uncertainty is about 0.04 ^{o}K. The polynomial expressions were differentiated with respect to pressure to obtain Joule-Thompson coefficients as a function of pressure.

Joule-Thompson coeffioients were calculated from these expressions. These experimental coefficients were compared with predicted Joule-Thompson coefficients from the Redlich-Kwong equations. Redlich-Kwong original proposal, Prausnitz method and Joffe suggestions to calculate the individual and interaction constants were considered. Four mixing rules were also used for each method

used in the Redlich-Kwong equation. The Redlich-Kwong equation studied by the guidelines of the original suggestions of Redlich and Kwong gave the best results for the mixture of Carbon Dioxide and Methane. The average deviations were 8.3% for Prausnitz versions, 7.0% for Joffe versions and 5.44% for the Redlich-Kwong original proposal.

These methods of correlation were compared with experimental compressibility factors found in the literature for two systems. One of the systems is composed of Methane, Ethane, Propane, Nitrogen and Carbon Dioxide. For this system the compressibility factors are well predicted by the three methods, even though the original Redlich-Kwong versions are slightly inferior. the other system is a CO_2-Propane mixture. For this system Prausnitz and Joffe versions can be considered as a good approach for predicting the PVT behavior, but the original Redlich-Kwong versions have to be discarded for this system.

These methods of correlation were also compared with the experimental Joule-Thompson coefficients reported by Stockett for mixtures of Nitrogen and Ethane. The maximum error and the average percent deviation were larger for this system than the maximum error and average percent deviation obtained for the system CO_2-Methane correlated by the present author.

INTRODUCTION

Since the classical work of van der Waals (1) in 1873 a large number of equations of state have appeared in the literature. Their degree of complexity, as indicated by the number of constants, has been deliberately increased to better represent the PVT behavior of substances over wide ranges of temperature and pressure. In this respect, the equation of state proposed by Martin and Hou (2) requires nine constants, the same equation of state has been modified in some cases to be a 17 constants equation of state. Similarly, the Benedict-Webb-Rubin (3) equation requires eight constants, while the Beattie-Bridgeman (4,5) equation uses five constants to predict the PVT behavior of a substance. More recently, an equation of state has been proposed by Pings and Sage (6), in the form of an orthogonal polynomial. Although good accuracy is claimed by these equations of state, the less complex equations of state having two constants, have been overlooked largely because of their lack of sophistication. This is consistent with the common notion that an equation with more constants should produce results that are more consistent with the experimental PVT behavior of a substance.

In 1949 Redlich and Kwong (7) proposed a two constant equation based on several theoretical and practical considerations. Their equation is rather empirical in nature but it furnishes satisfactory results above the critical temperature for pure components, and in some cases its applica-

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bility extends to the two phase region (8).

Such a simple and reliable equation of state is convenient for the study of gas mixtures, since only two mixing rules have to be applied. To date some work (9,10,11) has been done in applying this equation of state to mixtures.

This investigation proposed to provide experimental verification to the problem of extending the Redlich-Kwong equation of state to mixtures. The method used was to obtain experimental Joule-Thompson coefficients and compare these experimental results with values predicted by applying the Redlich-Kwong equation of state to the same mixture. In addition we checked the validity of these correlations with experimental compressibility factors given by Joffe and Zudkevitch for the saturated vapors of CO_2-Propane mixtures, with experimental compressibility factors for systems composed of Nitrogen, Methane, Ethane, Propane and Carbon Dioxide studied by Robinson and Jacoby, and finally, with experimental Joule-Thompson coefficients determined by Stockett for the system Nitrogen-Ethane.

HISTORICAL BACKGROUND

The experimental measurement of Joule-Thompson effects in gaseous systems dates back to the work of Joule and Thompson in the 19th century. Hoxton (12), Johnston (13), Brazinsky (14), Ahlert (15) and Juris (16), have summarized the work of various collaborators to 1971. Early workers had problems with heat leakage and kinetic effects, until Roebuck (19) developed a set of reliable data using a radial flow porous plug. In 1946, Johnston brought about significant modifications by building a monel valve with its valve seat and stem built from low conducting materials to minimize heat conduction through them,

Brazinsky came up with a modified version of Johnston's valve that has been used at pressures as high as 2500 psia. He also used a monel body to encase the valve, and the stem and valve seat were made from lucite. Furthermore, he incorporated a lucite sleeve in the downstream portion of the valve assembly to restrict heat leakage. Slight modifications were made to the valve by Stockett (18) and Ahlert. The same valve was used by the present author without any modification.

APPARATUS

The apparatus used in this experimental investigation was a closed circulating system equipped in such a way as to provide measurements of Joule-Thompson coefficients by means of an isenthalpic expansion as shown in Fig. 1. A schematic diagram of the valve used for the Joule-Thompson expansion is shown in Fig.2. Ahlert and Stockett describe how heat leakage from the high temperature side to the low temperature side and kinetic effects associated with expansion affect the accuracy of the data. Ahlert has also given a detailed description of the valve design, materials of construction and valve characteristics. Copper tubings were attached to the valve for pressure taps and thermocouple wires. The upstream and downstream pressures in the Joule-Thompson valve were measured with 12-inch-diameter Heise pressure gauges. Upstream and downstream temperatures were monitored with previously calibrated 30 BWG copper-constantan thermocouples and its emf's measured with a K-3 potentiometer.

Beginning with the compressor, the whole system consists of a dryer, heat exchanger used to cool the hot high pressure gas coming from the compressor with the low pressure gas coming from the Joule-Thompson valve, a cryostat bath used to heat or cool the incoming gas to a temperature close to the upstream valve temperature, the valve itself, the heat exchanger already mentioned, and, finally, three throttling val-

ves used to adjust the flow and regulate the inlet pressure to the compressor. A rotameter is used to measure the gas flow. A storage tank is located on a by-pass line and is used to store the gas sample to 200 psia. A vacuum pump is used to evacuate the whole system before feeding the sample. Also in the system are a Bayley controller that, in conjunction with liquid nitrogen flow (when needed) through a heat exchanger located in the cryostat bath, is used to maintain the cryostat bath temperature at the desired value.

PROCEDURE

A gas mixing apparatus was used to prepare the sample as described in Appendix A .

Before feeding the gas sample to the storage tank the whole system was evacuated to 1m.m. Hg., then experimental gas was used to flush the system. After flushing the system, the pressure in the system was increased to 10 psia. Again the system was evacuated, flushed and filled to a pressure of 10 psia three times and then the pressure in the storage tank was raised to 180 psia. This was enough to increase the upstream pressure to the desired value.

Precautionary measurements before starting the system involved checking the oil level of the compressor, opening of the cooling water valve, and filling the cold junction Dewar with ice. The potentiometer had to be standardized prior to any emf's recording.

Before starting the compressor, its inlet pressure was regulated to 10 psia. This measure was necessary to prolong the life of the diaphragms. Immediately upon starting the compressor, the inlet valve of the compressor was slightly open in order to mantain a constant inlet pressure of 10 psia. When the upstream pressure reached the desired value gas flow into the system was terminated, the necessary valves were immediately open to maintain circulation through the system. The valve was left operating in the open position for about an hour, time that was used to bring the upstream valve temperature to the desired value by means of the Bayley

controller and liquid nitrogen flow when needed. The valve was then partially closed to obtain the initial points of an isenthalp. The gas was again allowed to circulate for the time needed for equilibrium to be established. After reaching a new state of equilibrium, the upstream and downstream pressures and temperatures were recorded, the Joule-Thompson valve was closed a step further to obtain a new point of the isenthalp. This process was repeated until 7 or 8 points of the isenthalp were obtained. During the whole process of obtaining the isenthalp, the upstream pressure and temperature were mantained constant.

After the set of necessary measurements were recorded, the Joule-Thompson valve was open to equalize the upstream and downstream pressures of the valve. The flow control valves were operated, when doing this step, to mantain the compressor inlet pressure not higher than 10 psia. Gas from the system was then bled into the storage tank until a pressure of 250 psia at the high pressure side of the system was reached. The flow of gas from the system to the storage tank was then stopped and the compressor was turned off. A positive pressure was maintained in all the parts of the system to prevent air diffusion into the system. Finally the bath heater, temperature controller, bath stirrer, liquid nitrogen flow, compressor cooling water, and potentiometer were turned off.

EXPERIMENTAL JOULE-THOMPSON COEFFICIENT

The Joule-Thompson coefficient is defined by the following relation:

$$\mu = \left(\frac{\partial T}{\partial P}\right)_H$$

In order to obtain the Joule-Thompson coefficient with the discrete data points obtained, these data points were fitted to a least square correlation. A third order polynomial was used in this project, with the temperature picked as the dependent variable in the following form:

$$T = A + B P + C P^2 + D P^3$$

The equation obtained in this way was derived, and the Joule-Thompson coefficient is given by

$$\mu = B + 2 C P + 3 D P^2$$

FIGURE 1, DIAGRAM OF JOULE-THOMSON APPARATUS

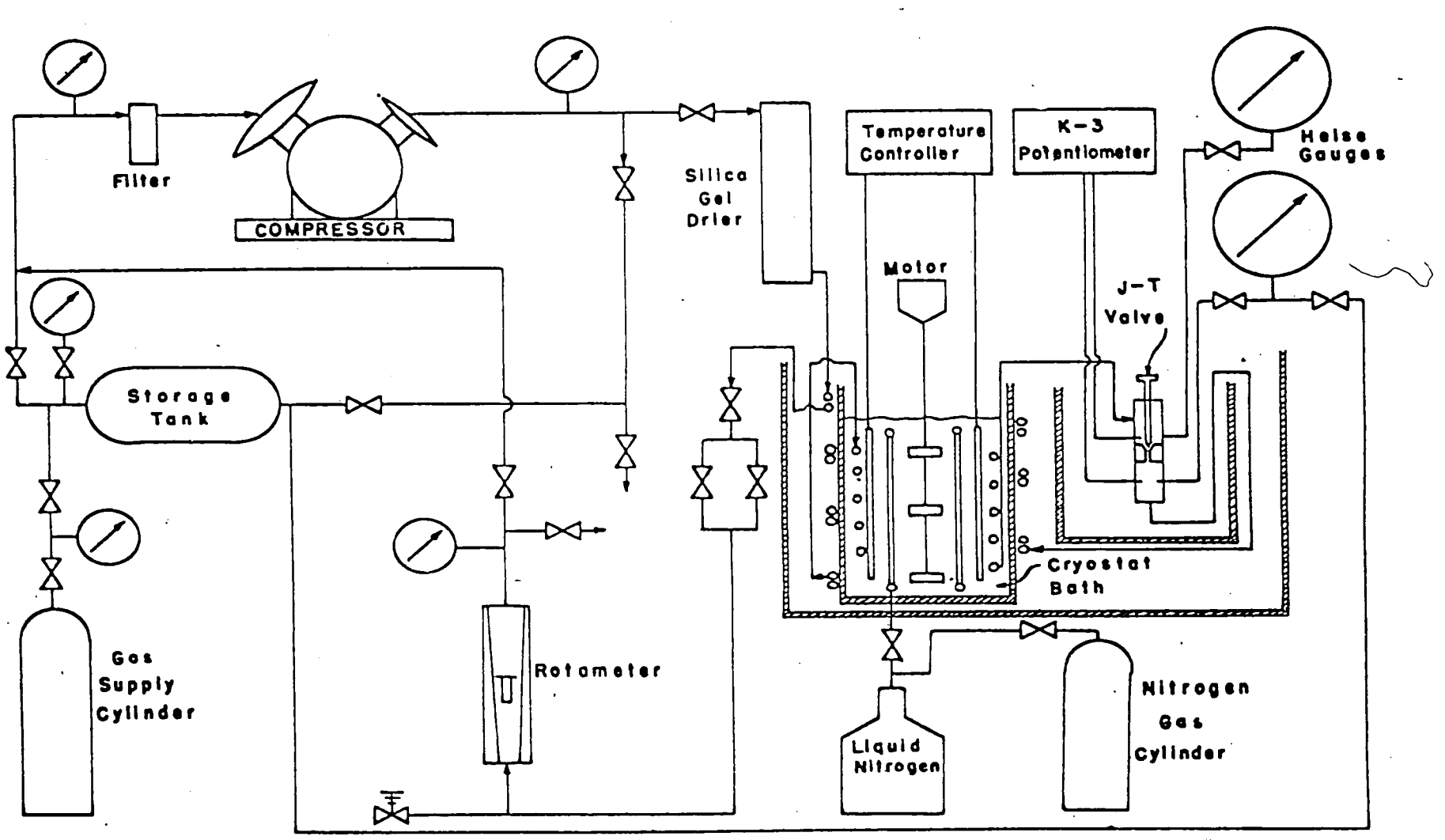
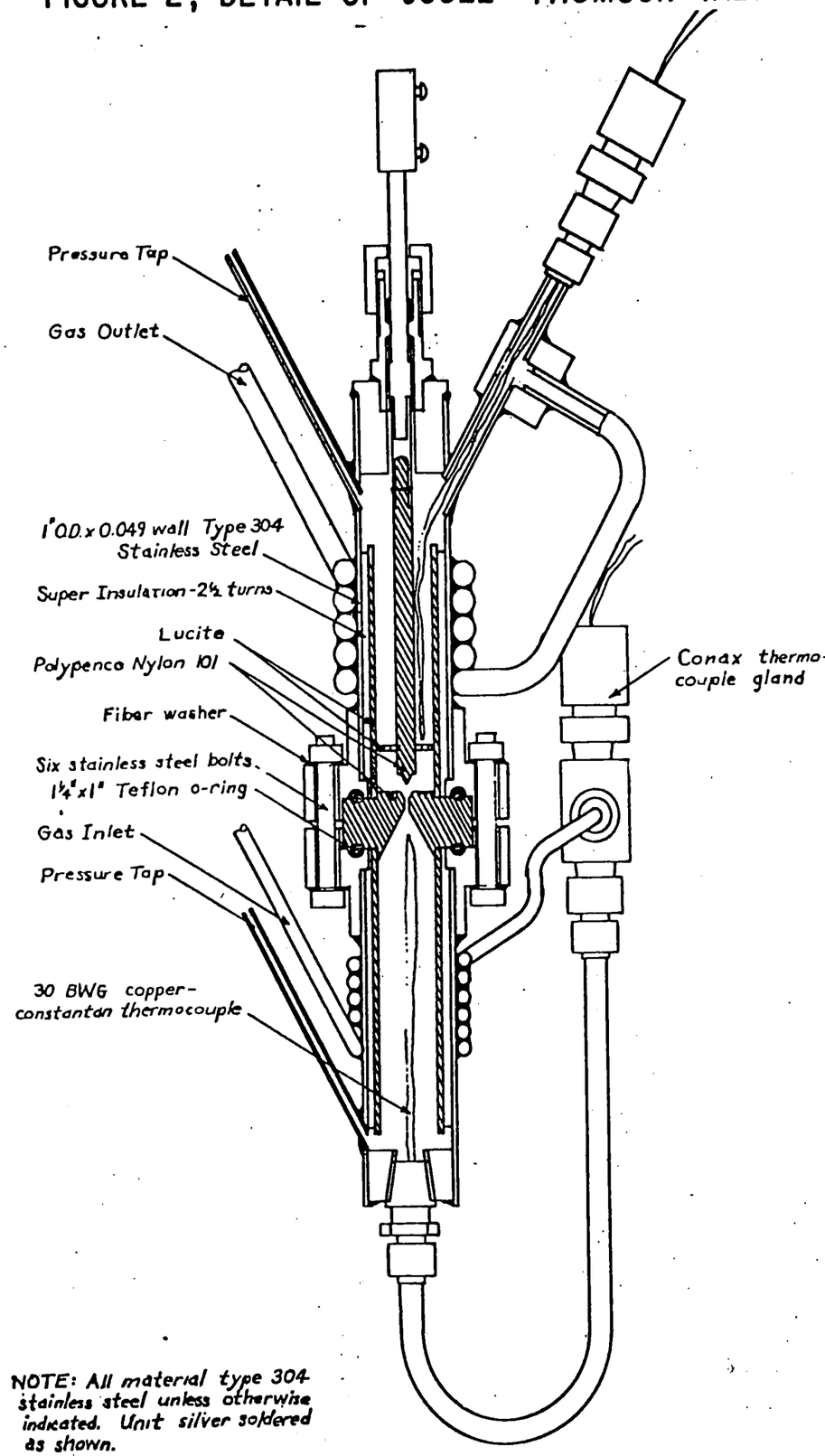


FIGURE 2, DETAIL OF JOULE - THOMSON VALVE



NOTE: All material type 304 stainless steel unless otherwise indicated. Unit silver soldered as shown.

THERMODYNAMICAL BACKGROUND

On essentially empirical grounds Redlich and Kwong (7) proposed an equation of state with only two constants in the form

$$P = \frac{R\,T}{V - b} - \frac{a}{T^{\frac{1}{2}}\,(V + b)\,V} \qquad (1)$$

$\underline{a}$ is given for a pure substance by

$$a = \Omega_a \frac{R^2\,T_c^{2.5}}{P_c} \qquad (2)$$

and $\underline{b}$ is given by

$$b = \Omega_b \frac{R\,T_c}{P_c} \qquad (3)$$

where $\Omega_a = 0.4278$ and $\Omega_b = 0.0867$ for all pure substances according to the original proposals. They also suggested the following mixing rules to obtain the values of $\underline{a}$ and $\underline{b}$ for a given mixture

$$b_{mix} = \sum y_i\, b_{ii} \qquad (4)$$

$$a_{mix} = \sum \sum y_i y_j\, a_{ij} \qquad (5)$$

a_{ij} is given by

$$a_{ij} = \sqrt{a_{ii}\, a_{jj}} \qquad (6)$$

Since the original proposal was made, several approaches have been tried to increase the accuracy of the Redlich-Kwong equation of state in predicting the PVT behavior of pure components as well as mixtures.

In 1964, G.M. Wilson (9) modified the Redlich-Kwong equation of state by introducing a temperature dependence for a_{ii}, the values of a for pure components. For a_{ij} he introduced the following correlation:

$$a_{ij} = \theta_{ij} a_{ij} + (1 - \theta_{ij}) a_{ij} \qquad (7)$$

and

$$a_{ii} = 4.934 \, R \, Tc_i^{1.5} \, (1 + K(1/Tr_i - 1))Tr_i^{1.5} b_i \qquad (8)$$

He also compared, favorably, his method with results obtained by applying the Benedict-Webb-Rubin equation of state to the same system.

A year later, Robinson and Jacoby (11) correlated compressibility factors for natural gases containing substantial amounts of N_2, CO_2 and H_2S by means of a modified version of the Redlich-Kwong equation of state. The a and b parameters for pure substances were found from experimental data, and their correlations for a and b took the forms

$$a/R^2 = \alpha + \beta (T - 311.0) \qquad (9)$$

$$b/R = \gamma + \delta (T - 311.0) \qquad (10)$$

They retained the Redlich-Kwong original suggestions for

mixtures:

$$b_{mix} = \sum y_i \, b_{ii} \qquad (11)$$

$$a_{mix} = \sum \sum y_i \, y_j \, a_{ij} \qquad (12)$$

but now, a_{ij} is given by

$$2 \, a_{ij} = K_{ij} \, a_{ii} + (1 - K_{ij}) \, a_{jj} \qquad (13)$$

where K_{ij} is a dimensionless parameter determined from experimental data of binary mixtures.

In the same year Redlich et al (17), proposed a rather complex empirical correction to the original R-K equation with considerable improvement for pure substances but with results not so clear for mixtures.

In the same year, Joffe and Zudkevitch (10), proposed the following procedure for mixtures containing light hydrocarbons and CO_2

a is obtained from the equation

$$a_{mix} = \sum \sum y_i y_j \, a_{ij} \qquad (12)$$

and b by

$$b_{mix} = \sum \sum y_i y_j \, a_{ij} \qquad (14)$$

where

$$a_{ij} = 0.4278 \, R^2 \, Tc_{ij}^{2.5} / Pc_{ij} \qquad (15)$$

and

$$b_{ij} = 0.0867 \, R \, Tc_{ij} / Pc_{ij} \qquad (16)$$

Substituting (15) and (16) in (12) and (14) it follows that

$$Tc_{mix}^{2.5} = Pc_{mix} \left(\sum\sum y_i y_j \, Tc_{ij}^{2.5} / Pc_{ij} \right) \quad (17)$$

$$Tc_{mix} = Pc_{mix} \left(\sum\sum y_i y_j \, Tc_{ij} / Pc_{ij} \right) \quad (18)$$

By knowing the pseudocritical temperature and presure of a binary system Tc_{ij} and Pc_{ij} can be found from (17) and (18). They applied this method to CO_2- light hydrocarbons mixtures with considerable improvement over the original Redlich-Kwong proposal.

In 1967, Chueh and Prausnitz (22) suggested several significant contributions to the Redlich-Kwong equation. a_{ii} and b_{ii} are again given by

$$a_{ii} = \Omega a_i \, R^2 \, Tc_i^{2.5} / Pc_i \quad (19)$$

$$b_{ii} = \Omega b_i \, R \, Tc_i / Pc_i \quad (20)$$

but now Ωa_i and Ωb_i are not the same for all substances. For mixtures they retained the original mixing rules

$$b_{mix} = \sum y_i \, b_{ii}$$

$$a_{mix} = \sum\sum y_i \, y_j \, a_{ij}$$

but

$$a_{ij} = \sqrt{a_{ii} \, a_{jj}}$$

instead, a_{ij} is given by

$$a_{ij} = \frac{(\Omega a_i + \Omega a_j) R^2 Tcij^{2.5}}{2 Pc_{ij}} \qquad (21)$$

where

$$Pc_{ij} = Zc_{ij} R Tc_{ij} / Vc_{ij} \qquad (22)$$

$$Vc_{ij}^{0.333} = \tfrac{1}{2} (Vc_i^{0.333} + Vc_j^{0.333}) \qquad (22\ a)$$

$$Zc_{ij} = 0.291 - 0.04 (w_i + w_j) \qquad (23)$$

$$Tc_{ij} = (1 - K_{ij}) (Tc_i Tc_j)^{\frac{1}{2}} \qquad (24)$$

The binary constant K_{ij} represents the deviation from the geometric mean for Tc_{ij}. To a good approximation K_{ij} is independent of temperature, pressure and composition. w is the accentric factor.

EXPERIMENTAL RESULTS

Joule-Thompson effects for Nitrogen and a mixture of CO_2-CH_4 were obtained over a temperature range of approximately -7 ^oC to 30 ^oC and a pressure range of 100 to 2000 psia. The composition of the mixture was 20.9 % CO_2 and 79.1 % Methane. The experimental data are giver for Nitrogen in table I and for the mixture in tables II to V. These experimental results are also shown graphically for Nitrogen in figure J1 and for the mixture in figures J2 to J5.

The purpose of the experimental Nitrogen isenthalp was to verify that the apparatus was capable of producing results in reasonable agreement with that of other investigators. The set of data points obtained in this research are within 1.5 % of the values obtained by Roebuck (20) and Ahlert.

Having obtained the experimental data points for each isenthalp, the data points were then fit to a least squares polynomial expression, the slope of which at any pressure gave the Joule-Thompson coefficient at that pressure. The average error between curve fit and experimental temperatures was 0.078 ^oC for all the runs.

TABLE Ia

NITROGEN ISENTHALP FOR 294.92 ^{o}K

AND 135.83 ATM.

PRESSURE, ATM	TEMPERATURE, ^{o}K			
	FUENTES	AHLERT	ROEBUCK	DIN
135.83	294.92	294.82		294.84
107.59	291.32	291.21		291.06
82.84	287.36	287.44		287.11
73.59	285.76	285.81		285.48
62.17	283.57	283.76	283.76	283.33
44.92	279.92	280.30	280.31	279.82
31.58	277.12	277.37	277.33	276.92
21.39	274.36	275.00	274.91	274.54

TABLE Ib

JOULE-THOMPSON COEFFICIENT FOR 294.92 ^{o}K

AND 135.83 ATM.

PRESSURE, ATM	JOULE-THOMPSON COEFFICIENT ^{o}K / ATM			
	FUENTES	AHLERT	ROEBUCK	DIN
135.83	0.110	0.116		0.119
107.59	0.144	0.142		0.147
82.84	0.173	0.167		0.182
73.59	0.184	0.177		0.194
62.17	0.198	0.190	0.189	0.194
44.92	0.219	0.210	0.213	0.212
31.58	0.235	0.227	0.231	0.226
21.39	0.247	0.240	0.246	0.237

FIGURE JI

EXPERIMENTAL NITROGEN ISENTHALP

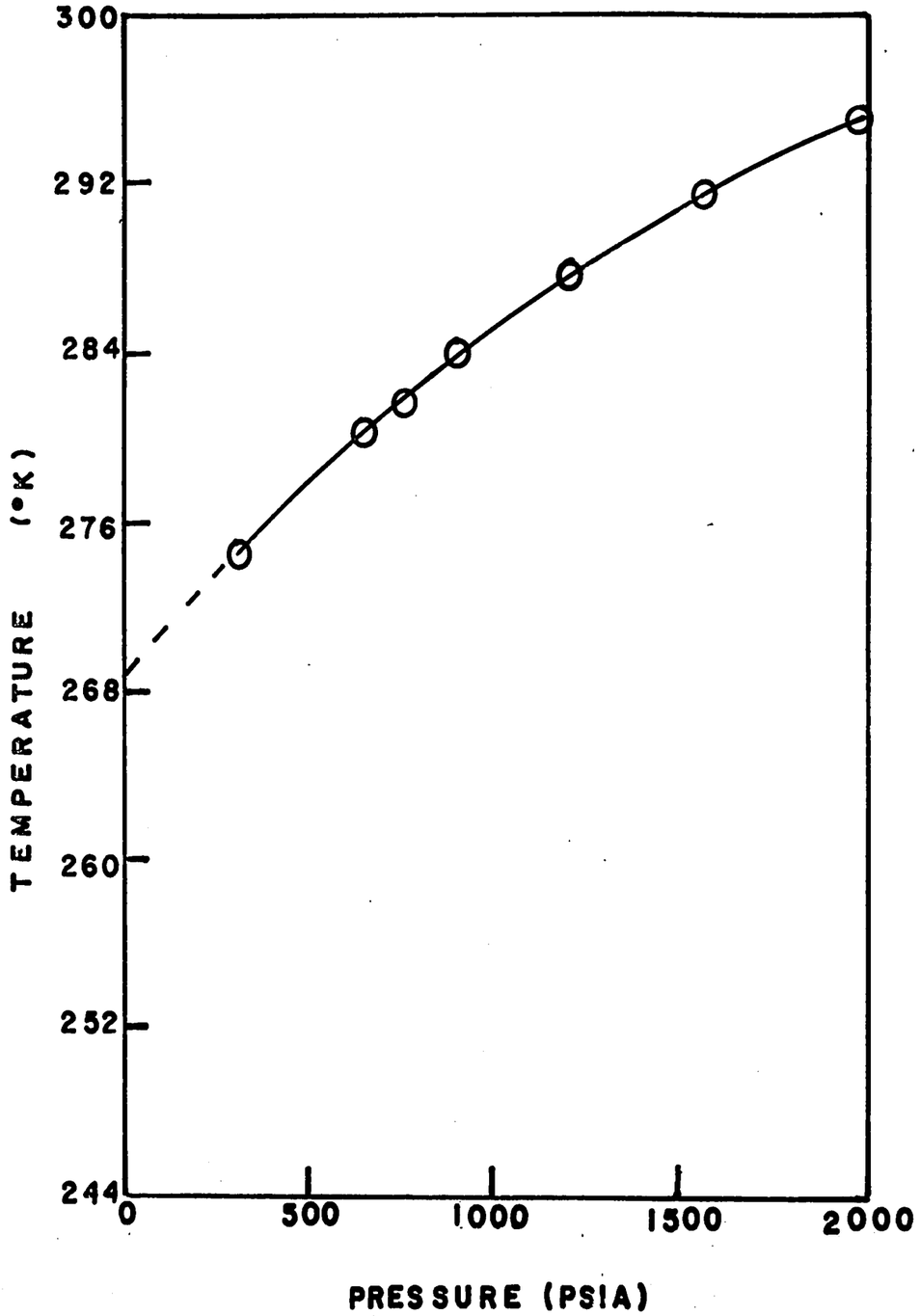


TABLE II

EXPERIMENTAL JOULE-THOMPSON COEFFICIENTS FOR THE SYSTEM CARBON DIOXIDE-METHANE

MOLAR FRACTION OF CO_2 = 0.209

P, ATM	T, KELVIN	μ, $^{o}K/ATM$
27.075	301.52	.487
23.571	299.74	.530
19.830	297.71	.565
12.687	293.49	.584
8.333	290.85	.605
5.554	289.14	.606
53.503	303.0.	.493
48.367	300.32	.520
40.782	296.30	.556
33.469	292.11	.588
27.483	288.55	.613
17.721	282.31	.649
7.483	275.55	.682
78.367	304.74	.449
55.714	293.42	.549
42.279	285.68	.606
28.673	276.97	.663
17.619	269.49	.708
9.388	263.46	.741

TABLE II (contd)

P, ATM	T, KELVIN	μ, ^{o}K/ATM
52.007	291.05	.559
40.884	285.08	.607
33.163	280.08	.640
25.442	275.24	.673
16.054	268.60	.714

FIGURE J2

EXPERIMENTAL ISENTHALP-20.9 PERCENT CO_2
FIRST RUN

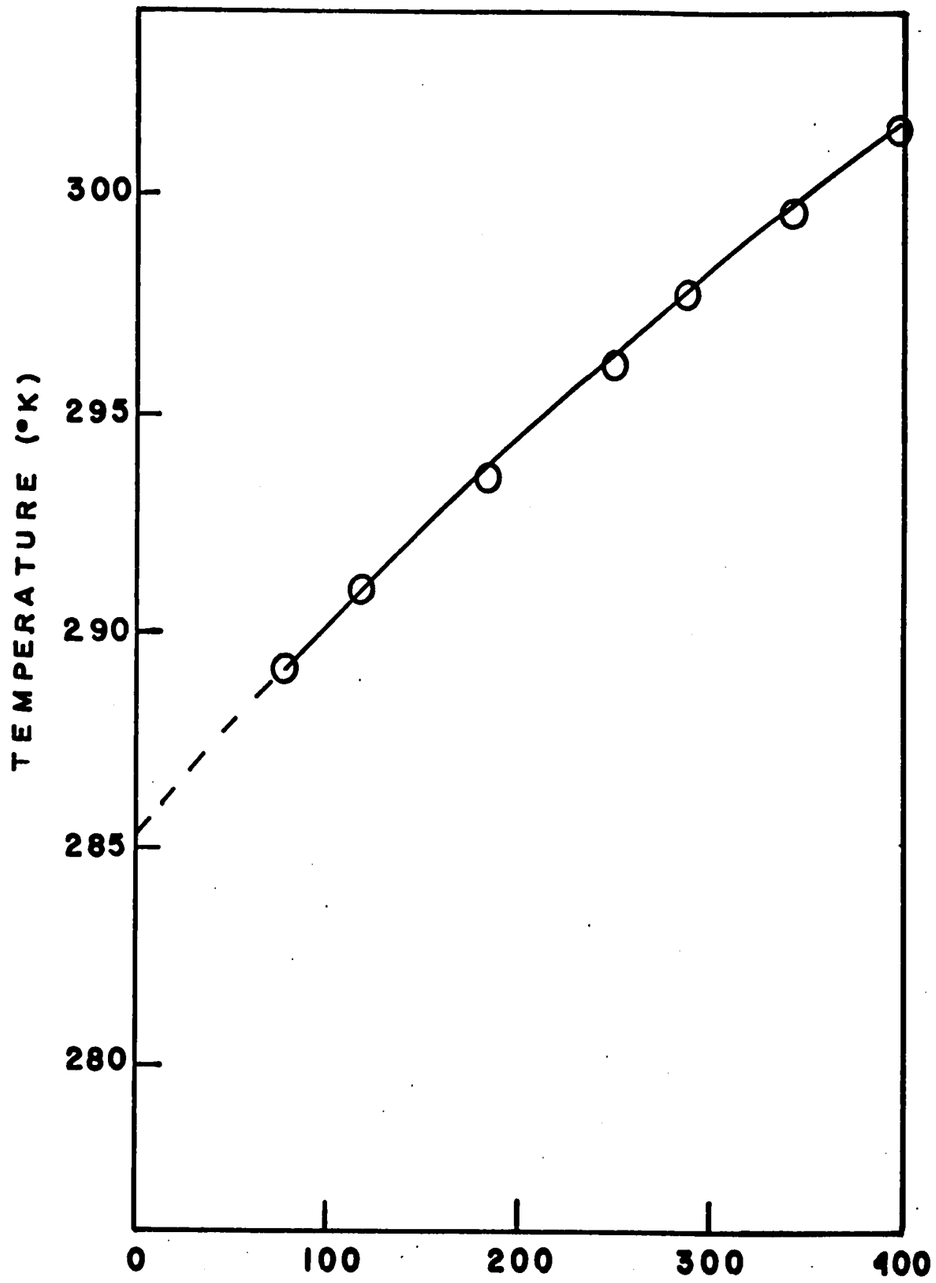


FIGURE J3

EXPERIMENTAL ISENTHALP- 20.9 PERCENT CO_2
SECOND RUN

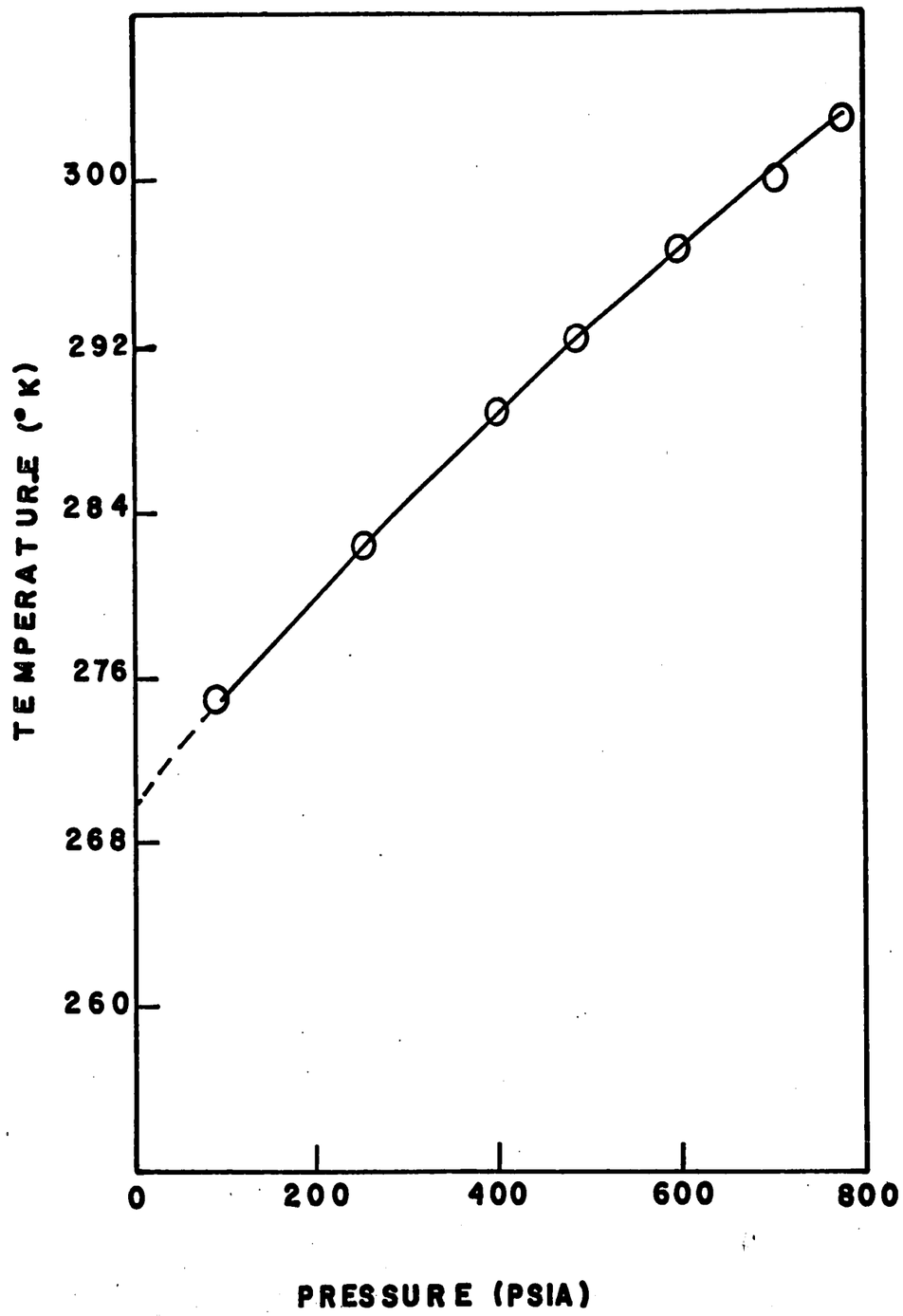


FIGURE J4

EXPERIMENTAL ISENTHALP-20.9 PERCENT CO_2
THIRD RUN

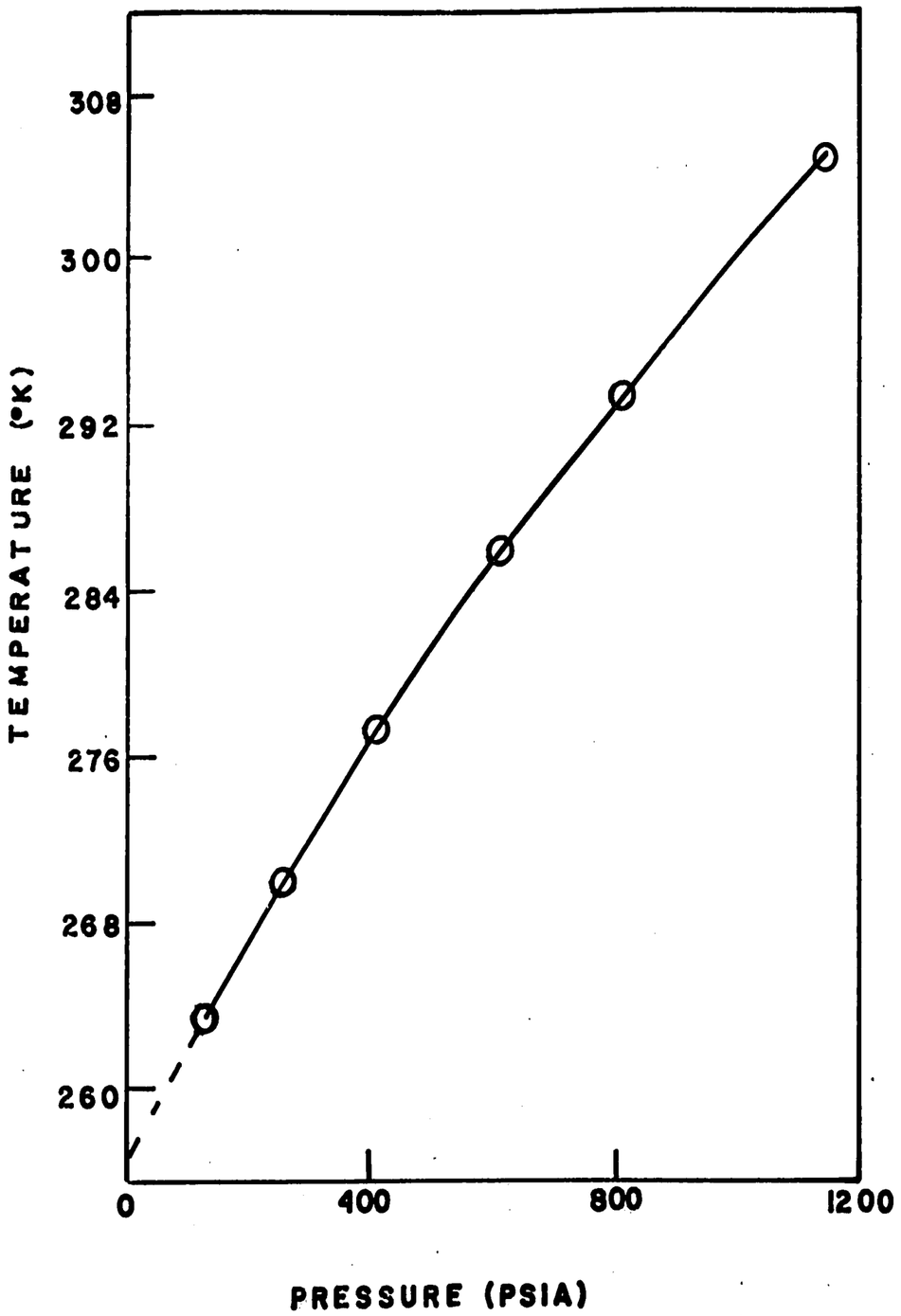
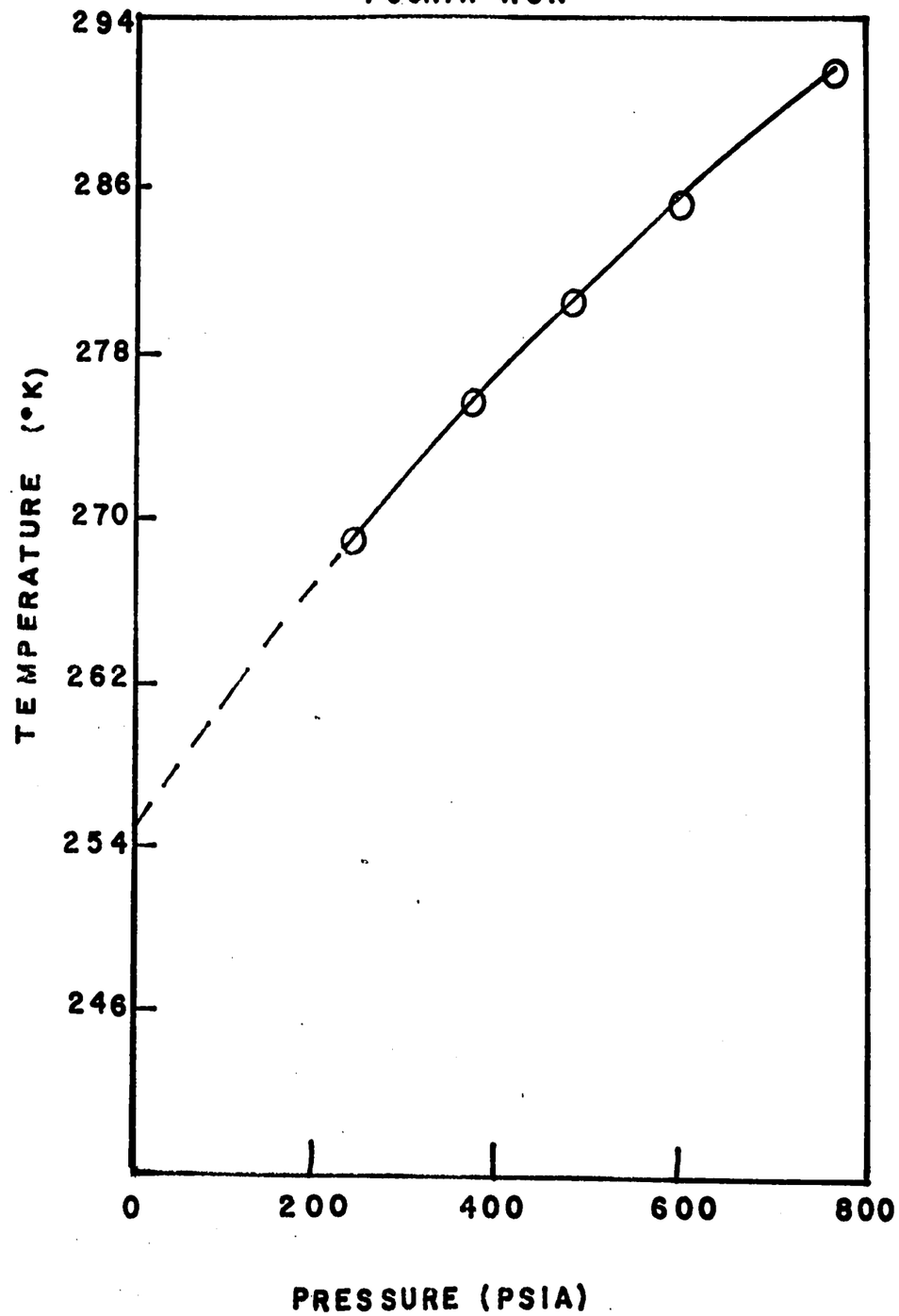


FIGURE J5

EXPERIMENTAL ISENTHALP-20.9 PERCENT CO_2
FOURTH RUN



CORRELATIVE STUDIES

Four versions of the Redlich-Kwong equation, based on the original Redlich-Kwong proposal were tested. The original proposal (VERSION 0) consists of:

a) To consider that $\underline{a}$ and $\underline{b}$ are given by the following expressions:

$$a_{ii} = 0.4278\ R^2\ Tc_i^{2.5} / Pc_i \qquad (25)$$

$$b_{ii} = 0.0867\ R\ Tc_i / Pc_i \qquad (26)$$

b)

$$b_{mix} = \sum y_i b_{ii}$$

$$a_{mix} = \sum\sum y_i y_j\ a_{ij}$$

where

$$a_{ij} = \sqrt{a_{ii}\ a_{jj}}$$

We proposed three modifications of this method: the first (VERSION 1) only differs from the original in the way b_{mix} is calculated, that now is given by:

$$b_{mix} = \sum\sum y_i y_j b_{ij} \qquad (27)$$

$$b_{ij} = \sqrt{b_{ii} b_{jj}} \qquad (28)$$

The second version (VERSION 2) introduces the Prausnitz parameters a_i and b_i for calculating $\underline{a}$ and $\underline{b}$ for pure components as in equations (19) and (20). For the mixed parameters, we proposed to calculate them as given by

$$a_{mix} = \sum\sum y_i y_j\ a_{ij}$$

$$b_{mix} = \sum y_i \, b_{ii}$$

a_{ij} is given again by $a_{ij} = \sqrt{a_{ii} \, a_{jj}}$

The last Redlich-Kwong version (VERSION 3) is esentially the same as the second, the only difference lies on the way how b_{mix} is calculated that now is given by

$$b_{mix} = \sum\sum y_i y_j \, b_{ij}$$

and

$$b_{ij} = \sqrt{b_{ii} \, b_{jj}}$$

We also studied the Prausnitz approach to the Redlich-Kwong equation. Prausnitz's original method begins by considering that a and b for pure components are given as follows:

$$a_{ii} = \Omega a_i \, R^2 \, Tc_i^{2.5} / Pc_i$$

$$b_{ii} = \Omega b_i \, R \, Tc_i / Pc_i$$

The mixed parameters are obtained from equations (21) to (24), and

$$a_{mix} = \sum \sum y_i y_j \, a_{ij}$$

$$b_{mix} = \sum y_i \, b_{ii}$$

The first version of the original Prausnitz's method to deal with the Redlich-Kwong equation is only a modification to the way how b_{mix} is calculated, that now is obtained from the following equation:

$$b_{mix} = \sum \sum y_i y_j \, b_{ij}$$

In the second version (VERSION 2)

$$a_{mix} = \sum\sum y_i y_j \, a_{ij}$$

$$b_{mix} = \sum\sum y_i y_j \, b_{ij}$$

and now

$$aij = \frac{(y_i \, \Omega a_i + y_j \, \Omega a_j)}{y_i + y_j} R^2 \, Tc_{ij}^{2.5} \, / \, Pc_{ij} \quad (29)$$

$$b_{ij} = \frac{(\, y_i \, \Omega b_i + y_j \, \Omega b_j \,)}{y_i + y_j} R \, Tc_{ij} \, / \, Pc_{ij} \quad (30)$$

The only modification introduced in VERSION 3 with respect to VERSION 3 is that now b_{mix} is given by

$$b_{mix} = \sum y_i \, b_{ii}$$

Joffe's method was the last one to be considered. The original proposal consisted of:

$$a_{ii} = 0.4278 \, R^2 \, Tc_i^{2.5} \, / \, Pc_i$$

$$b_{ii} = 0.0867 \, R \, Tc_i \, / \, Pc_i$$

for pure components, for mixtures they proposed

$$a_{mix} = \sum\sum y_i y_j \, a_{ij}$$

$$b_{mix} = \sum\sum y_i y_j \, b_{ij}$$

where

$$a_{ij} = 0.4278 \, R^2 \, Tc_{ij}^{2.5} \, / \, Pc_{ij}$$

$$b_{ij} = 0.0867 \, R \, Tc_{ij} \, / \, Pc_{ij}$$

In the section THERMODYNAMICAL BACKGROUND, the procedure

to find Tc_{ij} and Pc_{ij} and consequently a_{ij} and b_{ij} is explained.

The first version (VERSION 1) of Joffe, modified only the way of finding b_{mix}, that now is given by:

$$b_{mix} = \sum y_i \, b_{ii}$$

The second version (VERSION 2) introduced the Prausnitz parameters ${}^{\Omega}a_i$ and ${}^{\Omega}b_i$ to find a_{ii} and b_{ii},

$$a_{ii} = {}^{\Omega}a_i \, R^2 \, Tc_i^{2.5} / Pc_i$$

$$b_{ii} = {}^{\Omega}b_i \, R \, Tc_i / Pc_i$$

For mixtures, we adopted the procedure that follows:

$$a_{mix} = \sum \sum y_i y_j \, a_{ij}$$

$$b_{mix} = \sum \sum y_i y_j \, b_{ij}$$

And now

$$a_{ij} = \frac{y_i \, {}^{\Omega}a_i + y_j \, {}^{\Omega}a_j}{y_i + y_j} \, R^2 \, Tc_{ij}^{2.5} / Pc_{ij}$$

$$b_{ij} = \frac{y_i \, {}^{\Omega}b_i + y_j \, {}^{\Omega}b_j}{y_i + y_j} \, R \, Tc_{ij} / Pc_{ij}$$

The third Joffe version (VERSION 3) was essentially the same as the second, the only difference was the way to calculate a_{ij} and b_{ij}, that in the third version are given by

$$a_{ij} = ({}^{\Omega}a_i + {}^{\Omega}a_j) \, R^2 \, Tc_{ij}^{2.5} / 2Pc_{ij} \quad (31)$$

$$b_{ij} = \left(\Omega b_i + \Omega b_j \right) R\, Tc_{ij} / 2\, Pc_{ij} \quad (32)$$

DISCUSSION OF RESULTS

As has been indicated previously, four versions of the Prausnitz's method to deal with the Redlich-Kwong equation were studied. As seen from Table III, the original version (VERSION 0) and VERSION 1 produced the best results among the Prausnitz versions. It is interesting to note that VERSION 0 AND VERSION 1 produced results almost equal. The same equality holds for VERSIONS 2 and 3. The Joule-Thompson coefficients computed for the CO_2-Methane system by the use of the Prausnitz's version that produced the best results differ from the experimental results by an 8.30 average percent deviation. The maximum deviation was 10.4 percent and the minimum 2.88 per cent. Although surprising, the Prausnitz versions gave the worst results for the Joule-Thompson coefficients correlations of the system CO_2- Methane. A comparison of Prausnitz versions with Joffe and Redlich-Kwong versions is made in Fig. J6 to J9 for this system.

As it happened with Prausnitz versions, there are two pairs of Redlich-Kwong versions that are approximately identical for all purposes, In the case of VERSIONS 0 and 1 the results are identical in all the cases, and there are two discrepancies between VERSIONS 2 and 3. These discrepancies are almost insignificant, about 0.2% for both cases.

The Redlich-Kwong versions produced the best results with a 5.44 average percent deviation, the maximum deviation given by Redlich-Kwong VERSION 3, that produced the best

results, was 7.28 percent, and the minimum deviation was 0.18 percent.

There is only a pair of joffé versions (0 and 1) that produced results almost identical, but there is not much difference between the results produced by VERSIONS 2 and 3, VERSION 3 being slightly superior over VERSION 2 and furthermore VERSION 3 is better than all the Joffe versions. The average percent deviation given by Joffe VERSION 3 is 7 percent, that is 28.6 percent higher than the average deviation produced by the VERSIONS 2 or 3 of Redlich-Kwong, however Prausnitz's best version (VERSION 0 and 1) gives an average percent deviation that is 52.7 higher than that given by the best Redlich-Kwong version (VERSION 3).

All the deviations were calculated with respect to the experimental values reported in the following form:

$$\% \text{ Deviation} = \frac{\text{Experimental} - \text{Computed}}{\text{Experimental}} \times 100$$

and the average percent deviation was calculated as:

$$\text{Average Percent Deviation} = \frac{\sum_{i=1}^{K} \frac{\text{exp.} - \text{comp.}}{\text{exp}}}{K} \times 100$$

We also checked the validity of the methods devised in this research and in the original proposals with the experimental Joule-Thompson coefficients obtained by Stockett (18) for a mixture of Nitrogen and Methane. All the methods produce results comparable with each other and

TABLE III

COMPUTED JOULE-THOMPSON COEFFICIENTS FOR THE SYSTEM CARBON DIOXIDE-METHANE

MOLAR FRACTION OF CO_2 = 0.209

PRAUSNITZ VERSIONS

P, ATM	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
27.075	301.52	.501	.501	.498	.498
23.571	299.74	.510	.510	.508	.507
19.830	297.71	.521	.521	.518	.518
17.169	296.13	.529	.529	.526	.526
12.687	293.49	.542	.542	.539	.539
8.333	290.85	.555	.555	.552	.552
5.554	289.14	.563	.563	.561	.560
53.503	303.00	.465	.465	.463	.462
48.367	300.32	.482	.481	.479	.478
40.782	296.30	.507	.506	.504	.503
33.469	292.11	.531	.531	.529	.528
27.483	288.55	.552	.552	.549	.548
17.721	282.31	.586	.586	.583	.583
7.483	275.55	.622	.622	.619	.619
78.367	304.74	.417	.417	.415	.414
55.714	293.42	.497	.496	.494	.493
42.279	285.68	.548	.548	.545	.544
28.673	276.97	.603	.603	.600	.599
17.619	269.49	.648	.648	.645	.644
9.388	263.46	.683	.683	.679	.679

TABLE III (CONTD)

P, ATM	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
52.007	291.50	.510	.510	.508	.506
40.884	285.08	.553	.552	.550	.549
33.163	280.08	.584	.584	.581	.580
25.442	275.24	.614	.614	.611	.610
16.054	268.60	.654	.653	.650	.650

REDLICH-KWONG VERSIONS

P, ATM	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
27.075	301.52	.513	.513	.520	.520
23.571	299.74	.523	.523	.529	.529
19.830	297.71	.534	.534	.540	.540
17.169	296.13	.541	.541	.548	.548
12.687	293.49	.555	.555	.561	.561
8.333	290.85	.567	.567	.574	.574
5.554	289.14	.576	.576	.583	.583
53.503	303.00	.479	.479	.483	.483
48.367	300.32	.496	.496	.501	.502
40.782	296.30	.521	.521	.527	.527
33.469	292.11	.545	.545	.552	.552
27.483	288.55	.566	.566	.573	.573
17.721	282.31	.600	.600	.608	.608
7.483	275.55	.636	.636	.644	.644
78.367	304.74	.431	.431	.435	.435
55.714	293.42	.512	.512	.517	.518

TABLE III(CONTD)

P, ATM	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
42.279	285.68	.564	.564	.570	.570
28.673	276.97	.619	.619	.626	.626
17.619	269.49	.664	.664	.672	.672
9.388	263.46	.698	.608	.706	.706
52.007	291.50	.525	.525	.531	.531
40.884	285.08	.568	.568	.575	.575
33.163	280.08	.600	.600	.607	.607
25.442	275.24	.630	.630	.637	.637
16.054	268.60	.669	.669	.677	.677

JOFFE VERSIONS

P, ATM	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
27.075	301.52	.501	.502	.505	.505
23.571	299.74	.511	.512	.515	.515
19.830	297.71	.522	.522	.525	.525
17.169	296.13	.530	.530	.533	.533
12.687	293.49	.543	.543	.547	.547
8.333	290.85	.556	.556	.560	.560
5.554	289.14	.564	.564	.568	.568
53.503	303.00	.466	.468	.470	.469
48.367	300.32	.483	.484	.486	.486
40.782	296.30	.508	.509	.511	.511
33.469	292.1	.532	.533	.536	.536
27.483	288.55	.553	.554	.557	.557
17.721	282.31	.587	.588	.591	.591

TABLE III (CONTD)

P, ATM	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
7.483	275.55	.623	.623	.627	.627
78.367	304.74	.419	.421	.421	.421
55.714	293.42	.498	.500	.501	.501
42.279	285.68	.549	.551	.553	.553
28.673	276.97	.604	.605	.609	.608
17.619	269.49	.649	.650	.654	.654
9.388	263.46	.683	.684	.688	.688
52.007	291.50	.511	.513	.515	.515
40.884	285.08	.554	.555	.558	.558
33.163	280.08	.585	.586	.589	.589
25.442	275.24	.615	.616	.620	.620
16.054	268.60	.655	.655	.659	.659

FIGURE J6
EXPERIMENTAL AND CALCULATED JOULE-THOMSON COEFFICIENTS FOR THE CO_2- CH_4 SYSTEM
FIRST RUN

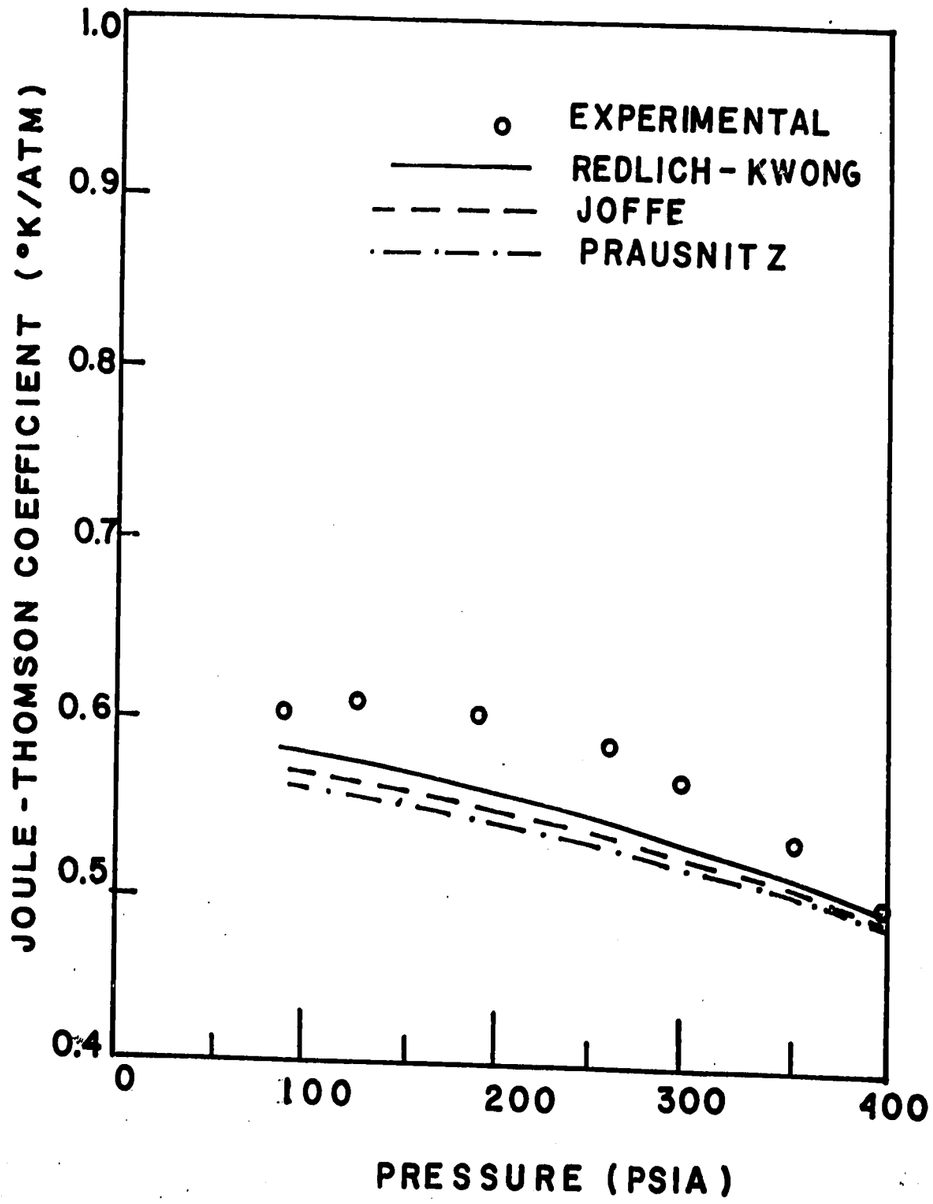


FIGURE J7
EXPERIMENTAL AND CALCULATED JOULE-THOMSON COEFFICIENTS FOR THE CO_2-CH_4 SYSTEM
SECOND RUN

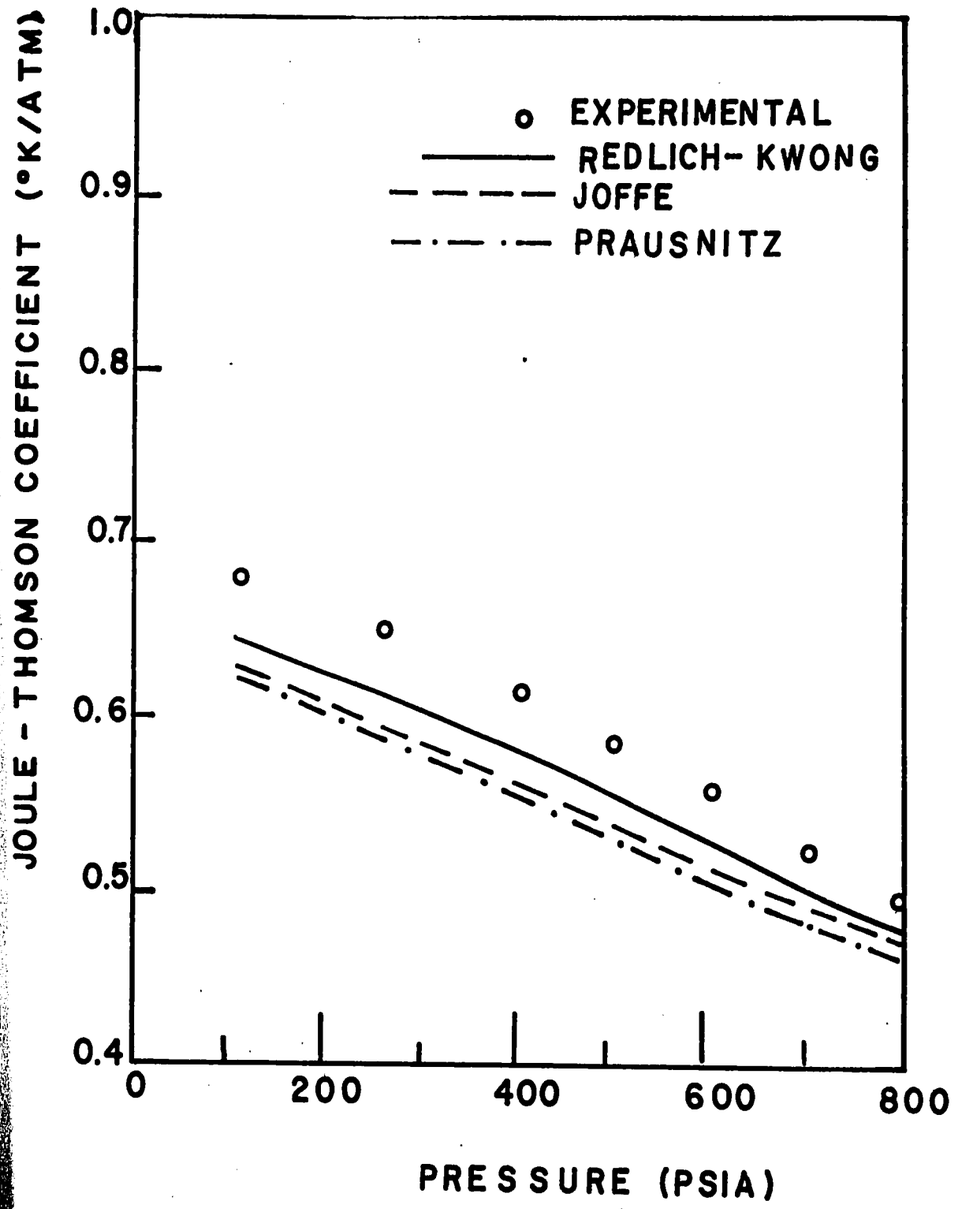


FIGURE J9
EXPERIMENTAL AN D CALCULATED JOULE-THOMSON COEFFICIENTS FOR THE CO_2-CH_4 SYSTEM
FOUTH RUN

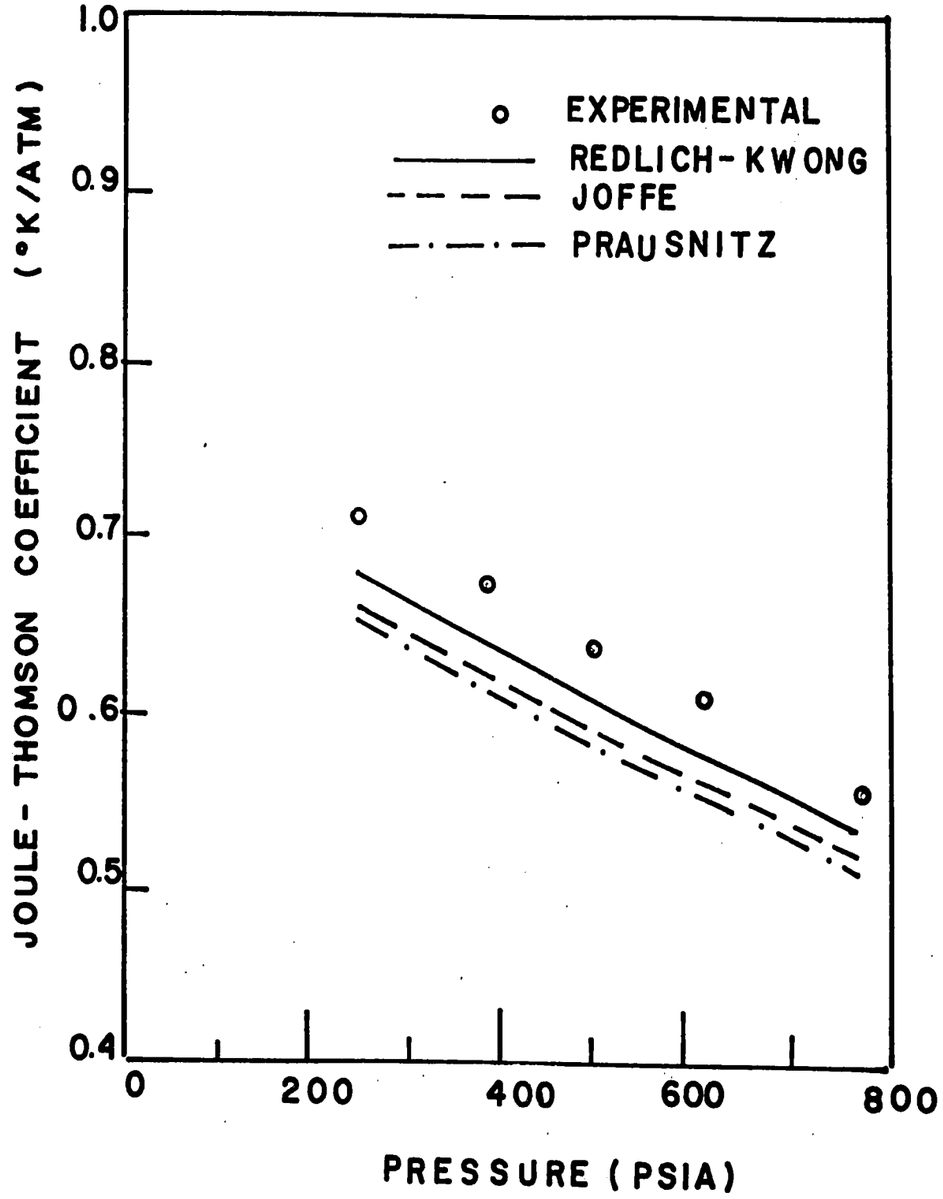
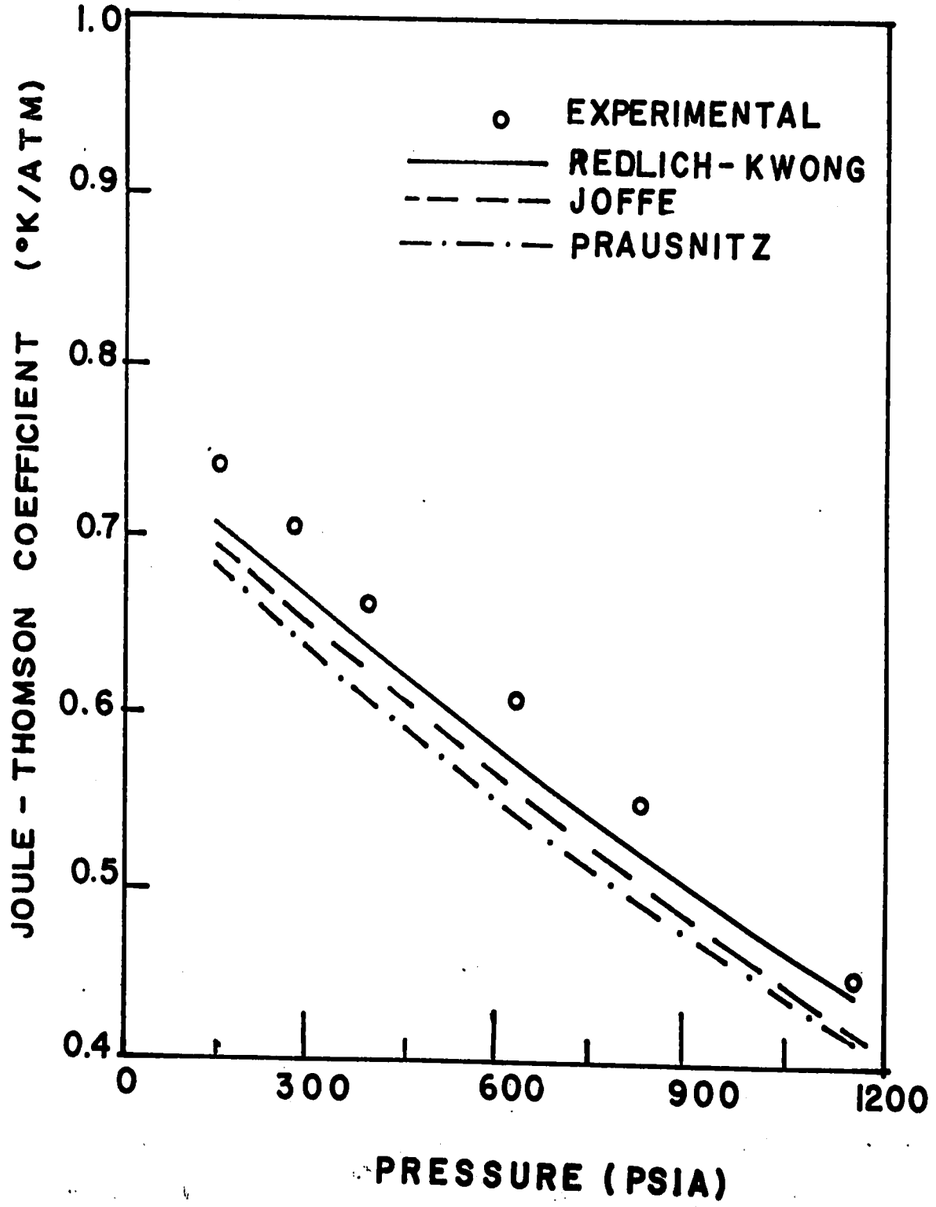


FIGURE J8
EXPERIMENTAL AND CALCULATED JOULE-THOMSON COEFFICIENTS FOR THE CO_2-CH_4 SYSTEM
THIRD RUN



there is no real advantage in using one method over the others. The deviations obtained when applying the different Redlich-Kwong versions to this system are large, the largest deviations being produced by the Redlich-Kwong equation. The Joffe and Prausnitz versions produced almost the same results: average percent deviation 4.71, maximum deviation 9.55% and minimum deviation was 1.82 percent. The Redlich-Kwong equation gave an average percent deviation of 5.8 percent, a maximum deviation of 15 percent and a minimum deviation of 3.1 percent. We did not try to correlate the low temperature data given by Stockett, that give the poorest correlation, since our heat cpacity data at zero pressure were valid above 273 ^{o}K. And this might be deceiving, because in some cases, Stockett obtained errors in the order of 25 percent and our maximum error is only 15 percent.

The next system to be studied is that studied by Robinson and Jacoby, for which they report the experimental compressibility factors. The system consisted of mixtures of methane, ethane, propane, carbon dioxide and nitrogen. The composition of the mixtures were changed to observe how the amount of CO_2 in the mixture influenced the PVT behavior predictability by the Redlich-Kwong equation. The temperature range for these mixtures was from 100 ^{o}F to 200 ^{o}F and the pressure range from 100 psia to 2000 psia.

Discarding the point at a pressure of 1570.0 psia for mixture 9 that exhibits an abnormal behavior, the original

(VERSION 0) and third (VERSION 3) Prausnitz versions produced very good results. The maximum deviation is only 1.1 per cent and in some cases, these versions reproduce the experimental results accurately. The average percent deviation is only 0.4 percent. The original Joffe version (VERSION 0) offers some advantage for the study of this five components system. This version produces results that are comparable with the results obtained by the Prausnitz versions that produced the best results for this same system. The maximum deviation is only 1.21 percent and the minimum 0.01 percent. The average percent deviation is only 0.52 . The Redlich-Kwong versions can not compare with Prausnitz or Joffe versions but they do not work so badly either. The maximum deviation is 3.6 percent, the minimum deviation is just 0.02 percent but the average percent deviation is 0.95.

Finally, the last system to be studied was also the most difficult to correlate. It consisted of different mixtures of carbon dioxide and propane near their dew point. All the Redlich-Kwong versions failed so badly, that even the version that predicted the less incorrect behavior was in error by 11 per cent in only two cases, and in the remaining 16 data points the errors were from 37 percent to 62.3 percent. Even though the compressibility factors obtained through the use of the Prausnitz versions were not as satisfactory in this case as in the five components system already studied, the maximum deviation is only 9 percent. That is a considerable improve-

ment over the original Redlich-Kwong version. The minimum deviation produced by the original Prausnitz version was 0.0 percent and the average percent deviation is 2.1 percent. Almost the same results are produced with the original Joffe version (VERSION 0). The maximum deviation is 9.6 percent, the minimum deviation is only 0.4 percent and the average deviation is 2.3 percent.

As summary, we can say that the original and third Prausnitz (VERSION 0 AND 3) and the original Joffe version (VERSION 0) produced the best results, and even though there are some mixed results, there is a very slight improvement in using VERSION 0 over VERSION 3 as given by Prausnitz for the study of some systems, especially in the correlation of compressibilty factors.

Although there is not general advantage of one method over the other, if we are to cope with an unknown system, the recommendation has to be for the use of Prausnitz orginal or third versions, since the constants needed to use the Redlich-Kwong equation are already known.

Another conclusion that we arrived to is that due to the differentiation that is needed to obtain the Joule-Thompson coefficients from the experimental data points obtained the error has to be greater than in the case of the calculation of compressibility factors.

The computed Joule-Thompson coefficients for the system Carbon Dioxide-Methane are always below the experimental values as can be observed in Fig. J2 to J5, but the computed Joule-Thomson coefficients for the system Nitrogen-

Methane are above the experimental values. This might be due to the conjugated effect of two different factors. The first is the difference in behavior exhibited by Carbon Dioxide in account of its quadrupole moment. This quadrupole moment is considered by Joffe one of the reasons to explain the inability of the original Redlich-Kwong equation to predict the PVT behavior of the Carbon Dioxide-Propane system. The second reason for the different behavior exhibited by the two mixtures might be due to the values of the constants Ωa and Ωb used to calculate the constants $\underline{a}$ and $\underline{b}$, and the uncertainity in the constant K_{ij} as given by Prausnitz. The constant K_{ij} is reported by Prausnitz to be equal to 0.05, with an uncertainty of $\pm$ 0.02. This uncertainity might explain the poor results obtained with the Prausnitz versions for the Carbon Dioxide-Methane system.

TABLE IV

ZERO PRESSURE HEAT CAPACITY EXPRESSIONS (24)

Nitrogen:

$$C^{o}p = 7.278152 - 2.357933 \times 10^{-3} T + 4.819276 \times 10^{-6} T^{2} - 1.884159 \times 10^{-9} T^{3}$$

Propane:

$$C^{o}p = 0.875587 + 6.088447 \times 10^{-2} T - 1.376161 \times 10^{-5} T^{2} - 7.282256 \times 10^{-9} T^{3}$$

Ethane:

$$C^{o}p = 3.827656 + 2.696468 \times 10^{-2} T + 1.290879 \times 10^{-5} T^{2} - 1.535507 \times 10^{-8} T^{3}$$

Methane:

$$C^{o}p = 7.348294 - 4.192432 \times 10^{-3} T + 3.335196 \times 10^{-5} T^{2} - 2.005523 \times 10^{-8}$$

Carbon dioxide:

$$C^{o}p = 4.661275 + 1.776032 \times 10^{-2} T - 1.334537 \times 10^{-5} T^{2} + 3.650326 \times 10^{-9} T^{3}$$

$C^{o}p$ = cal./g mole ^{o}K

$T = {}^{o}K$

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APPENDIX A

DERIVATION OF HEAT CAPACITY AND JOULE-THOMPSON COEFFICIENT EXPRESSIONS

An adiabatic expression is characterized by the fact that

$$dH = 0$$

By considering H as a function of temperature and pressure

$$dH = \left(\frac{\partial H}{\partial P}\right)_T dP + \left(\frac{\partial H}{\partial T}\right)_P dT \qquad (1)$$

hence, $\mu = \frac{\partial T}{\partial P}_H$ is given by

$$\mu = - \frac{\left(\frac{\partial H}{\partial P}\right)_T}{\left(\frac{\partial H}{\partial T}\right)_P} \qquad (2)$$

It can be shown that the above expression can be transformed to:

$$\mu = \frac{T \left(\frac{\partial V}{\partial T}\right)_P - V}{Cp} \qquad (3)$$

When using an explicit equation of state in P, equation (3) has to be modified to:

$$\mu Cp = \frac{T \left(\frac{\partial P}{\partial T}\right)_V}{\left(\frac{\partial P}{\partial V}\right)_T} - V \qquad (4)$$

After finding the partial derivatives in eq. (4) by use

of the Redlich-Kwong equation μCp is finally given by

$$\mu Cp = \frac{-\dfrac{R\,T}{V-b} - \dfrac{0.5\,a}{T^{\frac{1}{2}}\,V\,(V+b)}}{-\dfrac{R\,T}{(V-b)^2} + \dfrac{2aV+ab}{T^{\frac{1}{2}}\,V^2\,(V+b)^2}} - V \qquad (5)$$

Cp has to be evaluated at P and T. This was done with data obtained for Cpo, the heat capacity at zero pressure, and using the Redlich-Kwong equation of state in the following form:

$$\left(\frac{\partial Cv}{\partial V}\right)_T = T\left(\frac{\partial^2 P}{\partial T^2}\right)V \qquad (6)$$

$$\int_{Cvo}^{Cv} dCv = \int_{\infty}^{V} T\left(\frac{\partial^2 P}{\partial T^2}\right)_V dV \qquad (7)$$

or

$$\left(Cv\right)_{V=\infty} - \left(Cv\right)_{V=V} = +T\int_{V}^{\infty}\left(\frac{\partial^2 P}{\partial T^2}\right)_V dV \qquad (8)$$

$$\left(Cv\right)_{V=\infty} = Cvo = Cpo - R \qquad (9)$$

$$\left(Cv\right)_{V=V} = Cp - T\,\frac{\left(\dfrac{\partial P}{\partial T}\right)_V^2}{\left(\dfrac{\partial P}{\partial V}\right)_T} \qquad (10)$$

And so,

$$Cp = Cpo - R + T \frac{\left(\frac{\partial P}{\partial T}\right)_V^2}{\left(\frac{\partial P}{\partial V}\right)_T} - T\int_V^\infty \left(\frac{\partial^2 P}{\partial T^2}\right)_V dV \qquad (11)$$

Using the Redlich-Kwong equation of state to evaluate the partial derivatives needed, we arrive at:

$$Cp = Cpo - R + \frac{0.75\ a}{T^{1.5}\ b} \ln \frac{V + b}{V}$$

$$- \frac{T\left(\frac{R}{V-b} + \frac{0.5\ a}{T^{1.5}V(V+b)}\right)^2}{-\frac{R\ T}{(V-b)^2} + \frac{a(2V+b)}{T^{\frac{1}{2}}V^2(V+b)^2}} \qquad (12)$$

APPENDIX B

SAMPLE PREPARATION

The mixture of CO_2-Methane used in this research was prepared by means of a mixing apparatus existing in Lehigh University. A stainless steel cylinder used to store the gas sample was also used in its preparation. The cylinder already mentioned was joined to the mixing apparatus by copper tubing.

The initial step taken to prepare the samples was to evacuate the whole system to 50 microns of Hg., and to purge it with the minor component, this procedure was repeated twice, the minor component was then added until the desired pressure for this component was reached, after a reasonable period of time was allowed for reaching an equilibrium state, the pressure and temperature were recorded. Later the major component was added. Again equilibrium was allowed to establish itself and then, the final conditions were recorded.

Fifteen days were allowed, after the sample was made, for a complete mixing and homogeneity of the sample to occure before its use.

SAMPLE ANALYSIS

The analysis of the sample was made through the use of a Beckman model GC-2A chromatograph. A pressure counter connected to the chromatograph allowed accurate knowledge of each sample introduced into the chromatograph, and a thermometer capable of measuring to 0.01 degree Celsius permitted the pressure of each sample to be determined within $\pm$ 0.01 m.m. Hg.. The chromatograph was equipped with an electronic integrator. Its total registered counts were a quantitative representation of the area of each peak of the chromatogram.

The method used to analyze the gas mixture was to compare chtomatographically an unknown sample mixture with one of known composition. A gas mixing apparatus equipped with a pressure counter was used to prepare the standard samples. First, the standard sample container was evacuated and purged with the minor component, this procedure was repeated twice, the minor component was then added and after a reasonable period of time was allowed for equilibrium to be established, the pressure and temperature were recorded. Later the major component was added. Again equilibrium was allowed to establish itself and final conditions were recorded.

A P P E N D I X C

THERMOCOUPLE CALIBRATION

The thermocouples were calibrated by comparison with a Pt resistance thermometer certified by the National Bureau of Standards. The thermocouples were attached to the measuring portion of the resistance thermometer and the assembly was inmersed in a constant temperature bath. The resistance of the resistance thermometer was measured with a Mueller bridge and the thermocouple emf's with a K-3 potentiometer. The temperature was varied at intervals of 15 Centigrade degrees from -130 ^{o}C to 50 ^{o}C. The resistance and consequently the thermocouple emf's were related to temperature by means of an equation provided by the NBS for this resistance thermometer. The data obtained (T vs. emf's) were fitted by a third order polynomial and this was used to obtain a printout of temperature vs. emf at intervals of 0.01 ^{o}C. A maximum deviation of 1.5 mV is estimated to be the maximum that could be expected due to calibration.

Table C-1

Thermocouple Calibration

T, °C	Theromocouple 4 EMF	Thermocouple 5 EMF
-131.42	-4175.7	-4174.2
-112.05	-3678.8	-3680.3
- 92.169	-3124.8	-3122.7
- 87.14	-2977.1	-2980.2
- 81.57	-2805.9	-2810.1
- 76.15	-2643.2	-2648.4
- 70.74	-2473.9	-2478.5
- 65.89	-2315.6	-2315.9
- 56.40	-2006.8	-2008.4
- 45.50	-1642.0	-1643.0
- 35.00	-1283.5	-1283.5
- 22.71	- 843.7	- 843.8
- 9.51	- 354.4	- 354.6
6.52	253.7	253.1
23.55	897.4	897.6
31.56	1229.4	1227.4
42.27	1674.1	1673.2
48.58	1991.8	1990.3
53.83	2202.7	2202.6

APPENDIX D

TABLE D1

CRITICAL CONSTANTS FOR THE PURE COMPONENTS STUDIED

Substance	Pc, atm.	Tc, ^{o}K	Vc, lt./g mole
Carbon Dioxide	72.86	304.17	0.0943
Methane	45.78	191.06	0.0993
Ethane	48.16	305.44	0.1417
Propane	41.97	369.94	0.1985
Nitrogen	33.47	126.17	0.0899

All values taken from Prausnitz (21)

TABLE D2

PRAUSNITZ CONSTANTS FOR PURE COMPONENTS USED IN THE REDLICH-KWONG EQUATION

Substance	ω	Ω_a	Ω_b
Carbon Dioxide	0.225	0.447	0.0911
Methane	0.013	0.4278	0.0867
Ethane	0.105	0.4340	0.0880
Propane	0.152	0.4380	0.0889
Nitrogen	0.040	0.4290	0.0870

Values given in Prausnitz (21)

TABLE D3

PRAUSNITZ INTERACTION CONSTANTS K_{ij}

System	VALUE
CO_2-Methane	0.05
CO_2-Ethane	0.08
CO_2-Propane	0.11
CO_2-Nitrogen	0.08
Methane-Ethane	0.01
Methane-Propane	0.02
Methane-Nitrogen	0.03
Ethane-Propane	0.00
Ethane-Nitrogen	0.05
Propane-Nitrogen	0.09

Values taken from Prausnitz (23)

TABLE D4

Tc_{12} AND Pc_{12} USED IN JOFFE MODIFICATION OF THE REDLICH-KWONG EQUATION

Binary Mixture	Tc_{12}	Pc_{12}
CO_2-Methane	232.0	54.8
CO_2-Ethane	279.0	52.5
CO_2-Propane	292.0	44.8
CO_2-Nitrogen	201.0	49.2
Methane-Ethane	244.0	46.7
Methane-Propane	262.0	30.3
Methane-Nitrogen	140.3	33.0
Ethane-Propane	300.0	42.0
Ethane-Nitrogen	177.0	33.9
Propane-Nitrogen	230.0	35.0

Values taken from Joffe (10)

APPENDIX E

TABLE E1

EXPERIMENTAL VALUES OBTAINED BY JOFFE AND ZUDKEVITCH FOR THE SYSTEM CO_2-PROPANE

MIXTURE	Y_{CO_2}	P,PSIA	T, RANKINE	EXPER ZV
1	0.7238	750.0	560.0	0.573
2	0.7448	800.0	560.0	0.538
3	0.7647	850.0	560.0	0.498
4	0.7801	900.0	560.0	0.448
5	0.7908	950.0	560.0	0.387
6	0.7973	1000.0	560.0	0.312
7	0.5619	750.0	590.0	0.559
8	0.5806	800.0	590.0	0.527
9	0.5896	850.0	590.0	0.493
10	0.5968	900.0	590.0	0.454
11	0.5980	950.0	590.0	0.408
12	0.3218	650.0	620.0	0.537
13	0.3513	700.0	620.0	0.516
14	0.3743	750.0	620.0	0.496
15	0.3930	800.0	620.0	0.475
16	0.4068	850.0	620.0	0.453
17	0.4162	900.0	620.0	0.429
18	0.4202	950.0	620.0	0.391

TABLE E2

COMPUTED COMPRESSIBILITY FACTORS FOR THE SYSTEM CO_2-PROPANE FOLLOWING PRAUSNITZ GUIDELINES.

MIXTURE	VERSION 0	VERSION 1	VERSION 2	VERSION 3
1	0.573	0.559	0.558	0.570
2	0.540	0.522	0.521	0.537
3	0.504	0.479	0.476	0.499
4	0.456	0.409	0.406	0.449
5	0.392	0.320	0.319	0.380
6	0.340	0.296	0.297	0.333
7	0.562	0.545	0.544	0.561
8	0.531	0.508	0.508	0.530
9	0.487	0.452	0451	0.485
10	0.440	0.387	0.387	0.437
11	0.392	0.341	0.341	0.389
12	0.556	0.543	0.543	0.557
13	0.529	0.511	0.511	0.531
14	0.496	0.470	0.470	0.498
15	0.461	0.422	0.423	0.463
16	0.424	0.378	0.378	0.426
17	0.394	0.353	0.352	0.396
18	0.374	0.340	0.339	0.375

TABLE E3

COMPUTED COMPRESSIBILITY FACTORS FOR THE SYSTEM CO_2-PROPANE FOLLOWING KWONG GUIDELINES.

MIXTURE	VERSION 0	VERSION 1	VERSION 2	VERSION 3
1	0.451	0.167	0.199	0.174
2	0.203	0.176	0.208	0.184
3	0.212	0.185	0.217	0.193
4	0.219	0.194	0.225	0.202
5	0.225	0.202	0.232	0.211
6	0.231	0.209	0.238	0.218
7	0.242	0.192	0.239	0.199
8	0.245	0.201	0.245	0.208
9	0.246	0.209	0.249	0.216
10	0.250	0.216	0.254	0.224
11	0.254	0.224	0.259	0.232
12	0.476	0.201	0.400	0.205
13	0.272	0.211	0.259	0.216
14	0.266	0.220	0.263	0.226
15	0.268	0.229	0.268	0.234
16	0.271	0.236	0.274	0.242
17	0.276	0.244	0.279	0.250
18	0.280	0.251	0.284	0.258

TABLE E4

COMPUTED COMPRESSIBILITY FACTORS FOR THE SYSTEM CO_2-PROPANE USING JOFFE VERSIONS.

SYSTEM	VERSION 0	VERSION 1	VERSION 2	VERSION 3
1	0.588	0.587	0.562	0.563
2	0.558	0.557	0.527	0.529
3	0.525	0.524	0.487	0.489
4	0.482	0.480	0.433	0.436
5	0.419	0.414	0.363	0.365
6	0.342	0.337	0.325	0.325
7	0.573	0.572	0.551	0.551
8	0.543	0.542	0.518	0.519
9	0.500	0.498	0.471	0.471
10	0.450	0.446	0.421	0.421
11	0.392	0.387	0.376	0.375
12	0.568	0.568	0.549	0.548
13	0.542	0.541	0.520	0.520
14	0.510	0.508	0.485	0.485
15	0.473	0.470	0.447	0.447
16	0.431	0.428	0.409	0.409
17	0.394	0.390	0.382	0.382
18	0.368	0.365	0.365	0.365

APPENDIX F

TABLE F1

COMPUTED AND EXPERIMENTAL COMPRESSIBILITY FACTORS FOR THE SYSTEM NITROGEN-METHANE-ETHANE-PROPANE-CARBON DIOXIDE STUDIED BY ROBINSON AND JACOBY (11)

MIXTURE 6

T = 560 °R

COMPRESSIBILITY FACTORS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1549.9	.8666	.8671	.8667	.8667	.8672
1079.8	.8980	.8961	.8958	.8959	.8962
748.5	.9259	.9235	.9234	.9234	.9236
515.1	.9478	.9456	.9455	.9455	.9456
352.1	.9639	.9620	.9620	.9620	.9620

COMPRESSIBILITY FACTORS AS GIVEN BY REDLICH-KWONG VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1549.9	.8666	.8664	.8661	.8664	.8661
1079.8	.8980	.8956	.8955	.8956	.8954
748.5	.9259	.9232	.9231	.9232	.9231
515.1	.9478	.9454	.9453	.9453	.9453
352.1	.9639	.9619	.9619	.9619	.9619

TABLE F1 (Contd)

COMPRESSIBILITY FACTORS AS GIVEN BY JOFFE VERSIONS

P,PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1549.9	.8666	.8662	.8658	.8662	.8659
1079.8	.8980	.8954	.8952	.8954	.8952
748.5	.9259	.9231	.9229	.9231	.9229
515.1	.9478	.9618	.9618	.9618	.9618

MIXTURE 7

T = 560 ^{o}R

COMPRESSIBILITY FACTORS AS GIVEN BY PRAUSNITZ VERSIONS

P,PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1496.3	.8599	.8582	.8580	.8583	.8592
1045.8	.8940	.8905	.8904	.8907	.8912
726.3	.9235	.9200	.9199	.9201	.9204
500.3	.9463	.9433	.9432	.9434	.9436
342.3	.9630	.9605	.9605	.9606	.9607

COMPRESSIBILITY FACTORS AS GIVEN BY REDLICH-KWONG VERSIONS

P,PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1496.3	.8599	.8547	.8545	.8542	.8540
1045.8	.8940	.8881	.8880	.8877	.8875
726.3	.9235	.9184	.9183	.9180	.9180
500.3	.9463	.9422	.9422	.9420	.9419
342.3	.9630	.9598	.9598	.9597	.9596

TABLE F1 (Contd)

COMPRESSIBILITY FACTORS AS GIVEN BY JOFFE VERSIONS

P,PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1496.3	.8599	.8568	.8560	.8567	.8565
1045.8	.8940	.8895	.8890	.8894	.8893
726.3	.9235	.9193	.9190	.9192	.9191
500.3	.9463	.9428	.9426	.9428	.9427
342.3	.9630	.9602	.9601	.9602	.9602

MIXTURE 8

T = 560 ^{o}R

COMPRESSIBILITY FACTORS AS GIVEN BY PRAUSNITZ VERSIONS

P,PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1614.4	.8395	.8373	.8371	.8376	.8389
1134.1	.8772	.8728	.8727	.8732	.8739
791.6	.9107	.9064	.9063	.9067	.9072
547.5	.9370	.9334	.9334	.9337	.9339
375.7	.9564	.9536	.9536	.9538	.9539
256.2	.9702	.9680	.9680	.9682	.9683

COMPRESSIBILITY FACTORS AS GIVEN BY REDLICH-KWONG VERSIONS

P,PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1614.4	.8395	.8301	.8299	.8291	.8288
1134.1	.8772	.8680	.8678	.8670	.8668
791.6	.9107	.9032	.9031	.9025	.9024

TABLE F1 (Contd)

P,PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
547.5	.9370	.9313	.9313	.9308	.9307
375.7	.9564	.9522	.9522	.9518	.9518
256.2	.9702	.9671	.9671	.9669	.9669

COMPRESSIBILITY FACTORS AS GIVEN BY JOFFE VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1614.4	.8395	.8354	.8342	.8349	.8349
1134.1	.8772	.8715	.8708	.8711	.8711
791.6	.9107	.9056	.9051	.9053	.9053
547.5	.9370	.9329	.9326	.9327	.9327
375.7	.9564	9532	.9531	.9531	.9531
256.2	.9702	.9678	.9677	.9677	.9677

MIXTURE 9

T = 560 ^{o}R

COMPRESSIBILITY FACTORS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1570.0	.8722	.8170	.8169	.8175	.8189
1110.6	.8651	.8585	.8585	.8591	.8599
778.7	.9023	.8966	.8966	.8971	.8976
540.2	.9310	.9268	.9268	.9271	.9274
371.4	.9521	.9491	.9491	.9493	.9495
253.6	.9672	.9650	.9650	.9652	.9653

TABLE F1 (Contd)

COMPRESSIBILITY FACTORS AS GIVEN BY REDLICH-KWONG VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1570.0	.8722	.8062	.8060	.8043	.8040
1110.6	.8651	.8514	.8513	.8497	.8495
778.7	.9023	.8920	.8919	.8907	.8906
540.2	.9310	.9238	.9237	.9228	.9228
371.4	.9521	.9471	.9471	.9464	.9464
253.6	.9672	.9637	.9637	.9633	.9632

COMPRESSIBILITY FACTORS AS GIVEN BY JOFFE VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1570.0	.8722	.8146	.8130	.8134	.8132
1110.6	.8651	.8570	.8561	.8560	.8559
778.7	.9023	.8957	.8952	.8949	.8949
540.2	.9310	.9262	.9259	.9256	.9256
371.4	.9521	.9487	.9485	.9483	.9483
253.6	.9672	.9648	.9646	.9645	.9645

MIXTURE 10

T = 560 ^{o}R

COMPRESSIBILITY FACTORS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1703.1	.6668	.6641	.6648	.6647	.6632
1275.1	.7426	.7344	.7348	.7346	.7338

TABLE F1 (Contd)

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
936.5	.8113	.8038	.8040	.8038	.8034
672.0	.8659	.8601	.8602	.8601	.8599
472.9	.9065	.9024	.9024	.9023	.9022
328.1	.9354	.9327	.9328	.9327	.9326
225.4	.9560	.9540	.9540	.9540	.9539
153.8	.9699	.9687	.9688	.9687	.9687

COMPRESSIBILITY FACTORS AS GIVEN BY REDLICH-KWONG VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1703.1	.6668	.6423	.6421	.6354	.6350
1275.1	.7426	.7214	.7213	.7137	.7135
936.5	.8113	.7964	.7964	.7904	.7903
672.0	.8659	.8558	.8558	.8515	.8515
472.9	.9065	.8997	.8997	.8968	.8968
328.1	.9354	.9311	.9311	.9291	.9291
225.4	.9560	.9530	.9530	.9516	.9516
153.8	.9699	.9681	.9680	.9671	.9671

COMPRESSIBILITY FACTORS AS GIVEN BY JOFFE VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1703.1	.6668	.6634	.6593	.6568	.6517
1275.1	.7426	.7358	.7335	.7283	.7254
936.5	.8113	.8054	.8042	.7995	.7979
672.0	.8659	.8615	.8608	.8572	.8564

TABLE F1 (Contd)

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
472.9	.9065	.9034	.9030	.9004	.8999
328.1	.9354	.9334	.9332	.9314	.9311
225.4	.9560	.9545	.9544	.9531	.9530
153.8	.9699	.9691	.9690	.9682	.9680

MIXTURE 11

T = 610 ^{o}R

COMPRESSIBILITY FACTORS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1621.5	.8685	.8619	.8618	.8622	.8634
1129.6	.8999	.8932	.8932	.8936	.8943
782.5	.9272	.9220	.9219	.9223	.9227
538.2	.9486	.9447	.9447	.9449	.9452
367.8	.9642	.9616	.9615	.9617	.9619
250.1	.9754	.9736	.9736	.9737	.9738

COMPRESSIBILITY FACTORS AS GIVEN BY REDLICH-KWONG VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1621.5	.8685	.8525	.8525	.8512	.8509
782.5	.8999	.8872	.8870	.8858	.8856
538.2	.9272	.9180	.9179	.9169	.9168
367.8	.9641	.9599	.9598	.9593	.9592
250.1	.9754	.9725	.9724	.9721	.9720

TABLE F1 (Contd)

COMPRESSIBILITY FACTORS AS GIVEN BY JOFFE VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1621.5	.8685	.8596	.8579	.8585	.8580
1129.6	.8999	.8918	.8908	.8908	.8905
782.5	.9272	.9210	.9204	.9203	.9201
538.2	.9486	.9441	.9437	.9436	.9435
367.8	.9641	.9612	.9609	.9608	.9607
250.1	.9754	.9733	.9732	.9731	.9730

MIXTURE 12

T = 660 ^{o}R

COMPRESSIBILITY FACTORS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1559.2	.9031	.8952	.8953	.8955	.8962
1075.8	.9268	.9199	.9199	.9202	.9206
739.0	.9468	.9418	.9419	.9420	.9423
505.1	.9625	.9589	.9590	.9591	.9593
343.6	.9740	.9715	.9715	.9716	.9717
233.0	.9821	.9804	.9804	.9805	.9806

COMPRESSIBILITY FACTORS AS GIVEN BY REDLICH-KWONG VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1559.2	.9031	.8874	.8873	.8859	.8858
1075.8	.9268	.9148	.9147	.9135	.9134

TABLE F1 (Contd)

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
739.0	.9468	.9385	.9385	.9375	.9374
505.1	.9625	.9568	.9567	.9560	.9560
343.6	.9821	.9795	.9795	.9791	.9791

COMPRESSIBILITY FACTORS AS GIVEN BY JOFFE VERSIONS

P, PSIA	EXP ZV	VERS 0	VERS 1	VERS 2	VERS 3
1559.2	.9031	.8938	.8925	.8927	.8922
1075.8	.9268	.9191	.9183	.9181	.9178
739.0	.9468	.9413	.9409	.9406	.9404
505.1	.9625	.9586	.9583	.9581	.9580
343.6	.9740	.9713	.9711	.9709	.9709
233.0	.9821	.9803	.9802	.9801	.9800

TABLE F2

COMPOSITION OF MIXTURES ANALYZED BY ROBINSON AND JACOBY

MOLAR FRACTIONS

MIXTURE	CO_2	CH_4	C_2H_6	C_3H_8	N_2
6	.0004	.9740	.0153	.0008	.0095
7	.0536	.9222	.0149	.0009	.0084
8	.1146	.8616	.0146	.0004	.0088
9	.1972	.7830	.0139	.0004	.0055
10	.5446	.4460	.0068	.0000	.0026
11	.2230	.7559	.0140	.0021	.0050
12	.2814	.6993	.0106	.0005	.0082

APPENDIX G

TABLE G1

EXPERIMENTAL VALUES FOR THE SYSTEM NITROGEN-ETHANE AS GIVEN BY STOCKETT (18)

MIXTURE 1

MOLAR FRACTION OF NITROGEN = 0.9490

P, PSIA	T, KELVIN	μ, ^{o}K/ATM
50.0	287.56	.258
100.0	288.43	.253
200.0	290.11	.242
400.0	293.27	.222
800.0	298.74	.180
50.0	277.28	.276
100.0	278.21	.271
200.0	280.02	.262
400.0	283.47	.245
800.0	289.66	.210

MIXTURE 2

MOLAR FRACTION OF NITROGEN = 0.8570

P, PSIA	T, KELVIN	μ, ^{o}K/ATM
50.0	284.24	.337
100.0	285.38	.330
200.0	287.58	.317
400.0	291.72	.291
800.0	298.93	.239

TABLE G1 (CONTD)

MIXTURE 3

MOLAR FRACTION OF NITROGEN = 0.775

P, PSIA	T, KELVIN	μ, ^{o}K/ATM
50.0	286.67	.408
100.0	288.05	.400
200.0	290.71	.382
400.0	295.66	.347
1200.0	279.98	.306
1600.0	287.42	.243
2000.0	293.36	.197
2400.0	298.26	.166

MIXTURE 4

MOLAR FRACTION OF NITROGEN = 0.5690

P, PSIA	T, KELVIN	μ, ^{o}K/ATM
50.0	281.52	.569
100.0	283.42	.552
200.0	287.07	.515
400.0	293.69	.454
1200.0	283.05	.445
1600.0	293.54	.334

TABLE G2

COMPUTED JOULE-THOMPSON COEFFICIENTS FOR THE SYSTEM NITROGEN-ETHANE ANALYZED BY STOCKETT (18)

MIXTURE 1

MOLAR FRACTION OF NITROGEN = 0.9490

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	287.56	.273	.273	.273	.272
100.0	288.43	.267	.268	.268	.267
200.0	290.11	.257	.258	.258	.257
400.0	293.27	.238	.239	.238	.237
800.0	298.74	.201	.202	.202	.201
50.0	277.28	.294	.294	.294	.293
100.0	278.21	.288	.289	.288	.288
200.0	280.02	.277	.278	.277	.277
400.0	283.47	.255	.256	.256	.255
800.0	289.66	.215	.216	.215	.214

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY REDLICH-KWONG VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	287.56	.278	.278	.279	.279
100.0	288.43	.273	.273	.274	.274
200.0	290.11	.262	.263	.263	.264

TABLE G2 (CONTD)

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
400.0	293.27	.243	.243	.244	.244
800.0	298.74	.206	..207	.207	.207
50.0	277.28	.299	.299	.300	.301
100.0	278.21	.293	.294	.295	.295
200.0	280.02	.282	..283	.283	.284
400.0	283.47	.261	.261	.262	.262
800.0	289.66	.220	.220	.220	.221

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY JOFFE VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	287.56	.271	.271	.271	.272
100.0	288.43	.265	.266	.266	.267
200.0	290.11	.255	.256	.256	.257
400.0	293.27	.236	.237	.237	.237
800.0	298.74	.200	.200	.200	.201
50.0	277.28	.292	.292	.292	..293
100.0	278.21	.286	.286	.287	.287
200.0	280.02	.275	.275	.276	.276
400.0	283.47	.253	.254	.254	.254
800.0	289.66	.213	.214	.213	.214

MIXTURE 2

MOLAR FRACTION OF NITROGEN = 0.8570

TABLE G2 (CONTD)

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	284.24	.347	.348	.347	.346
100.0	285.38	.340	.341	.341	.339
200.0	287.58	.327	.329	.328	.327
400.0	291.72	.302	.304	.303	.301
800.0	298.93	.255	.257	.257	.254

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY REDLICH-KWONG VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	284.24	.360	.360	.362	.363
100.0	285.38	.353	.354	.355	.356
200.0	287.58	.340	.341	.342	.343
400.0	291.72	.414	.316	.316	.318
800.0	298.93	.266	.268	.268	.270

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY JOFFE VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	284.24	.342	.343	.344	.345
100.0	285.38	.336	.337	.337	.338
200.0	287.58	.323	.324	.324	.325
400.0	291.72	.298	.299	.299	.300
800.0	298.93	.251	.252	.251	.253

TABLE G2 (CONTD)

MIXTURE 3

MOLAR FRACTION OF NITROGEN = 0.7750

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	286.67	.405	.405	.406	.404
100.0	288.05	.397	.399	.398	.396
200.0	290.71	.382	.384	.383	.381
400.0	205.66	.352	.355	.354	.352
1200.0	279.98	.303	.308	.308	.302
1600.0	287.42	.240	.245	.244	.239
2000.0	293.36	.188	.193	.193	.188
2400.0	298.26	.147	.151	.151	.147

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY REDLICH-KWONG VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	286.67	.421	.423	.425	.426
100.0	288.05	.414	.415	.417	.418
200.0	290.71	.399	.400	.402	.403
400.0	295.66	.369	.371	.372	.374
1200.0	279.98	.320	.324	.321	.326
1600.0	287.42	.253	.258	.254	.258
2000.0	293.36	.199	.202	.199	.203
2400.0	298.26	.156	.160	.155	.159

TABLE G2 (CONTD)

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY JOFFE VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	286.67	.398	.400	.401	.402
100.0	288.05	.391	.392	.393	.394
200.0	290.71	.376	.377	.378	.379
400.0	295.66	.346	.348	.348	.350
1200.0	279.98	.296	.300	.297	.301
1600.0	287.42	.234	.238	.234	.238
2000.0	293.36	.183	.187	.183	.187
2400.0	298.26	.143	.147	.143	.146

MIXTURE 4

MOLAR FRACTION OF NITROGEN = 0.5690

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY PRAUSNITZ VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	281.52	.605	.607	.607	.605
100.0	283.42	.595	.597	.597	.594
200.0	287.07	.574	.577	.577	.574
400.0	293.69	.533	.537	.537	.532
1200.0	283.05	.446	.456	.456	.446
1600.0	293.54	.328	.336	.336	.327

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY REDLICH-KWONG

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	281.52	.625	.626	.631	.633

TABLE G2 (CONTD)

P,PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
100.0	283.42	.615	.617	.621	.623
200.0	287.07	.594	.597	.600	.603
400.0	293.69	.553	.557	.559	.563
1200.0	283.05	.468	.477	.469	.479
1600.0	293.54	.342	.350	.342	.350

JOULE-THOMPSON COEFFICIENTS AS GIVEN BY JOFFE VERSIONS

P, PSIA	T, KELVIN	VERS 0	VERS 1	VERS 2	VERS 3
50.0	281.52	.595	.596	.600	.601
100.0	283.42	.584	.586	.590	.592
200.0	287.07	.563	.566	.569	.572
400.0	293.69	.522	.525	.527	.530
1200.0	283.05	.434	.442	.436	.443
1600.0	293.54	.319	.326	.319	.326

VITA

Carmelo Fuentes L. was born in Magangue, Colombia on September 26, 1942 to Sebastian and Ana Fuentes. He attended Liceo Bolivar, Colegio Loperena and Simon Araujo Secondary Schools in Colombia. He received the degree of Ingeniero Quimico from Universidad del Atlantico in Barranquilla, Colombia in 1966.

From 1965 to 1972 Mr. Fuentes taught at the Universidad del Atlantico. In 1972 he was awarded a scholarship from Laspau to study at Lehigh University.

Mr. Fuentes is still working at the Universidad del Atlantico, and he holds membership in the Colombian Institute of Chemical Engineers.